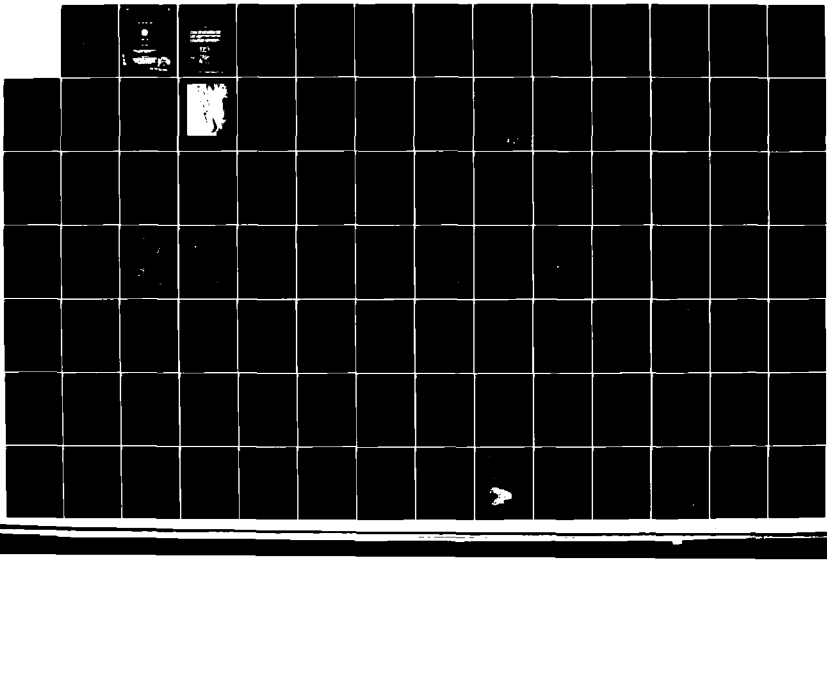
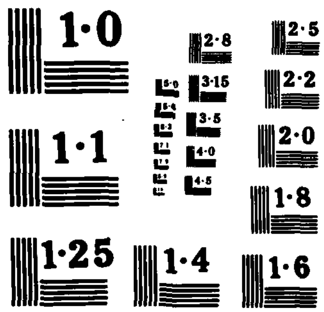
AD-A156 710 US COAST GUARD HYBRID CONCEPT(U) GRUMMAN AEROSPACE CORP 1/2
BETHPAGE NY C HERMANNS ET AL. AUG 84 USCG-D-6-85
DTCG23-84-F-20024

UNCLASSIFIED F/G 13/10 NL




1·0
2·8
2·5
3·15
2·2
3·5
4·0
2·0
1·1
4·5
1·8
1·25
1·4
1·6

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-6-85		

4. Title and Subtitle

U. S. COAST GUARD HYBRID CONCEPT

5. Report Date
AUGUST 1984

6. Performing Organization Code

8. Performing Organization Report No.

7. Author(s)
C. HERMANNS, R. WRIGHT-G.A.C.; J. MEYER-DTNSRDC

9. Performing Organization Name and Address
DAVID W. TAYLOR NAVAL SHIP R&D CENTER, CODE 1233
BETHESDA, MD 20084; GRUMMAN AEROSPACE CORPORATION
NAVAL SHIP SYSTEMS DEPARTMENT
BETHPAGE, NEW YORK 11714

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTCG23-84-F-20024

13. Type of Report and Period Covered
FINAL REPORT

12. Sponsoring Agency Name and Address
UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT (G-DMT/54)
WASHINGTON, D. C. 20593

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract THIS REPORT PROVIDES A FEASIBILITY ANALYSIS OF THE APPLICATION OF A PHYSICALLY WELL-DEFINED BUOYANCY/FUEL TANK AND HYDROFOIL SYSTEM TO A SPECIFIC CRAFT, AN EXISTING USCG 95-FOOT WPB. THE PURPOSE OF THIS MODIFICATION IS TO ENHANCE THE CRAFT'S MISSION CAPABILITIES IN TERMS OF SPEED, RANGE/ENDURANCE AND MOTIONS IN A SEAWAY. IT IS CONCLUDED THAT THE CONCEPT (DESIGN M174) IS TECHNICALLY FEASIBLE, HAS MERIT, AND PROVIDES CONSIDERABLE IMPROVEMENT OVER THAT OF THE WPB, PARTICULARLY IN THE AREAS OF SPEED, RANGE, AND MOTIONS. THE 181.3 LONG TON DESIGN IS ALL STEEL, HAS 2 PIELSTICK DIESEL ENGINES AND CARRIES 38.1 TONS OF USABLE FUEL IN ADDITION TO A MISSION LOAD OF 15 TONS. FULL LOAD MAXIMUM SPEED IS 34.0 KNOTS, MAXIMUM FOILBORNE ENDURANCE IS 53 HOURS AT 22.5 KNOTS, AND MAXIMUM RANGE IS 1,314 NAUTICAL MILES AT 27.5 KNOTS. HULLBORNE RANGE AT 12.5 KNOTS IS 2,594 N. MILES. THERE IS ADEQUATE FUEL (WITH A 10% RESERVE) TO CARRY OUT A 5-DAY MISSION OF 24 HOURS AT 30 KNOTS, PLUS 96 HOURS AT 13 KNOTS FOR A TOTAL RANGE OF 1,968 N. MILES.

ADDITIONAL STUDIES ARE REQUIRED IN CONJUNCTION WITH A DETAILED DESIGN OF SUCH A DEMONSTRATOR. IT IS RECOMMENDED THAT A NEW DESIGN (SIMILAR TO M174) BE INVESTIGATED IN WHICH THE UPPER HULL WOULD BE MODIFIED TO IMPROVE INTACT STABILITY, OVERALL STRUCTURAL EFFICIENCY, AND THE MACHINERY ROOM LAYOUT. ALSO, AN OPTIMUM PROPELLER SHOULD BE DESIGNED TO ACCOMMODATE THE ENTIRE FOILBORNE SPEED REGIME.

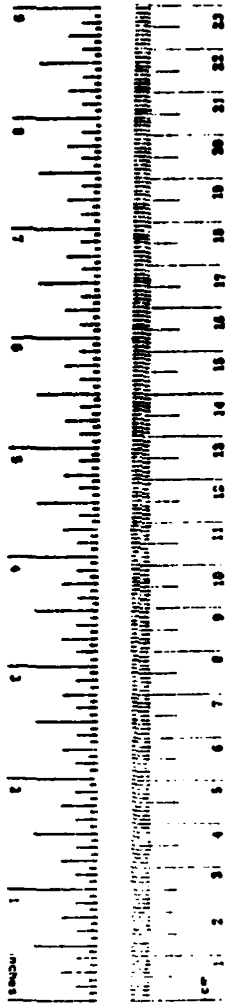
17. Key Words	18. Distribution Statement
HYDROFOIL, HYBRID, HYSWAS, SMALL WATER-PLANE AREA, STRUT, FOILS.	DOCUMENT IS AVAILABLE TO THE U. S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	173	

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

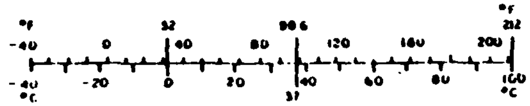


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

<u>LIST OF SYMBOLS</u>

A	Foil aspect ratio or propeller disk area
B	Buoyancy
b	Foil span
C_D	Drag coefficient, D/qS
$C_{D\ i}$	Aerodynamic induced drag coefficient
$C_{D\ L}$	Coefficient for drag due to lift,
$C_{D\ P}$	Parasite drag coefficient
$C_{D_{surf}}$	Free surface image drag coefficient
$C_{D\ wake}$	Drag coefficient for incremental wake drag (over minimum wake drag)
$C_{D\ wave}$	Wave drag coefficient
C_L	Lift coefficient, L/qS
C_{L_α}	Lift curve slope, C_L/α
C_p	Propeller power coefficient, P/qAV
C_S	Propeller speed-power coefficient, $(\rho/Pn^2)^{1/5}V$
C_T	Propeller thrust coefficient, T/qA
C	Chord
C_{avg}	Average chord
C_l	Foil section lift coefficient
$(C_l)_i$	Foil section lift coefficient due to incidence lift
$(C_l/C_L)_i$	Ratio of section/foil lift for incidence lift
C_{pod}	Chord at foil/pod intersection
C_r	Chord at foil plane of symmetry (inside tank)
C_t	Chord at foil tip
D	Drag, or propeller diameter

LIST OF SYMBOLS (contd.)

D_i	Aerodynamic induced drag
E	Endurance
E_S	Specific endurance
EHP	Effective horsepower, TV/550=DV/550(1-t)
G	Non-dimensionalized circulation Γ/bV
g	Acceleration of gravity, 9.8066 m/s^2 (32.174 ft/sec^2)
J	Propeller advance ration, V/nD
K_Q	Propeller torque coefficient, $P/2\pi\rho n^3D^5$
K_T	Propeller thrust coefficient, $T/\rho n^2D^4$
L	Dynamic lift, Δ-B; for foil or craft, depending on context
ΔL	Incremental lift due to normal acceleration in turn
L_T	Lift in long tons
L/D	Lift/drag ratio
L/S	Foil Loading
ℓ	Foil base, longitudinal distance between fwd. and aft MAC's, $\ell_1+\ell_2$
ℓ_1,ℓ_2	Longitudinal distance between CG and fwd and aft foil MAC's respectively
MAC	Foil mean aerodynamic chord
M_F	Foil rolling moment
N	Propeller RPM
NM	Nautical Mile
n	Propeller rps
P	Propeller power, 550 SHP η_G
q	Dynamic pressure, $\rho V^2/2$

LIST OF SYMBOLS (cont.)

R	Range or turn radius
R_S	Specific range
S	Foil area, for craft (S_1+S_2) or individual foil, depending on context
S_1, S_2	Fwd and aft foil area respectively
S'	Exposed foil area
SHP	Engine shaft horsepower
SFC	Specific fuel consumption
SSF	Ship's Service Fuel Flow
T	Thrust, $D/(1-t)$
t	Thrust deduction factor
V	Craft speed
V_K	Craft Speed in knots
w	Propeller wake factor
Y_B	Vertical distance between C.G. and center of buoyancy
Y_S	Lateral load on strut
α	Foil angle of attack
Γ	Circulation, m^2/S (ft^2/sec), or foil dihedral
Δ	Displacement
δ	Flap angle
δ_1	A generalized control angle; pitch, incidence, or full chord flap angle
η	Span station measured from foil plane of symmetry and expressed as fraction of semi-span or propeller efficiency, C_T/C_P
η_G	Transmission efficiency

LIST OF SYMBOLS (cont)

η_I Ideal propeller efficiency, $2/(\sqrt{1+C_T}+1) = 2(\sqrt{1+C_T}-1)/C_T$

η_{pod} Span station at foil/pod intersection

Λ Quarter-chord sweep angle

Λ_{LE} Leading edge sweep angle

$\Lambda_{3c/4}$ 3/4 chord (flap hinge line) sweep angle

λ Taper ration, C_t/C_r

ρ Density, 1,025.87 NS^2/m^4 (1.9905 lbs sec^2/ft^4)

σ_i Prandtl biplane factor, $C_{D\ surf}/C_{D_i}$ and approximation for foil wave drag/section wave drag

ϕ Roll angle

$\dot{\psi}$ turn rate

4.0 Performance Summary

POWER	DYNAMIC LIFT LONG TONS	DISPLACEMENT LONG TONS	MAX. SPEED KNOTS
CONTINUOUS @ 5920 SHP	98.23	181.33	34.0
	76.20	159.30	36.2
INTERMITTENT @ 6500 SHP	98.23	181.33	35.8
	76.20	159.30	37.7

FOILBORNE RANGE AND ENDURANCE

DISPLACEMENT	MAX. SPECIFIC RANGE		MAX.	MAX. SPECIFIC ENDURANCE		MAX.
LONG TONS	R_s NM/TON	SPEED KNOTS	RANGE (N.MI)	E_s HRS/TON	SPEED KNOTS	END (HRS)
181.33	38.3	27.5	1310	1.54	22.5	51.4
159.30	48.5	25.0	1660	2.20	20.0	75.5

Mission: 24 hours @ 30 kts. + 96 hours @ 12 kts. @ 164 tons

Range = 1968 NM

Fuel Burned = 34.3 Tons

Fuel Available = 38.11 Tons useable less 3.81 Tons margin

= 34.3 Tons

Notes:

1. 159.30 Ton displacement is with 42% of mission fuel remaining
2. Wake deduction, w = 5%
3. Thrust deduction, t = 5%
4. Drag margin = 11%
5. Gear efficiency = 95%
6. Takeoff thrust margin = 43% @ 22.5 kts. @ 181.33 Tons @ intermittent Power
7. Increasing propeller diameter from 53" to 58" should improve 22.5 knot range and endurance about 5%.

SECTION 4
PERFORMANCE

of the tank. They are not, however, considered significant enough to appreciably alter the results. A table containing the input offsets is provided in Appendix A. While it may appear from the isometric view that the strut extends the full length of the tank, in reality the "y" coordinate of the strut offsets equals zero in the forward and aft extremities.

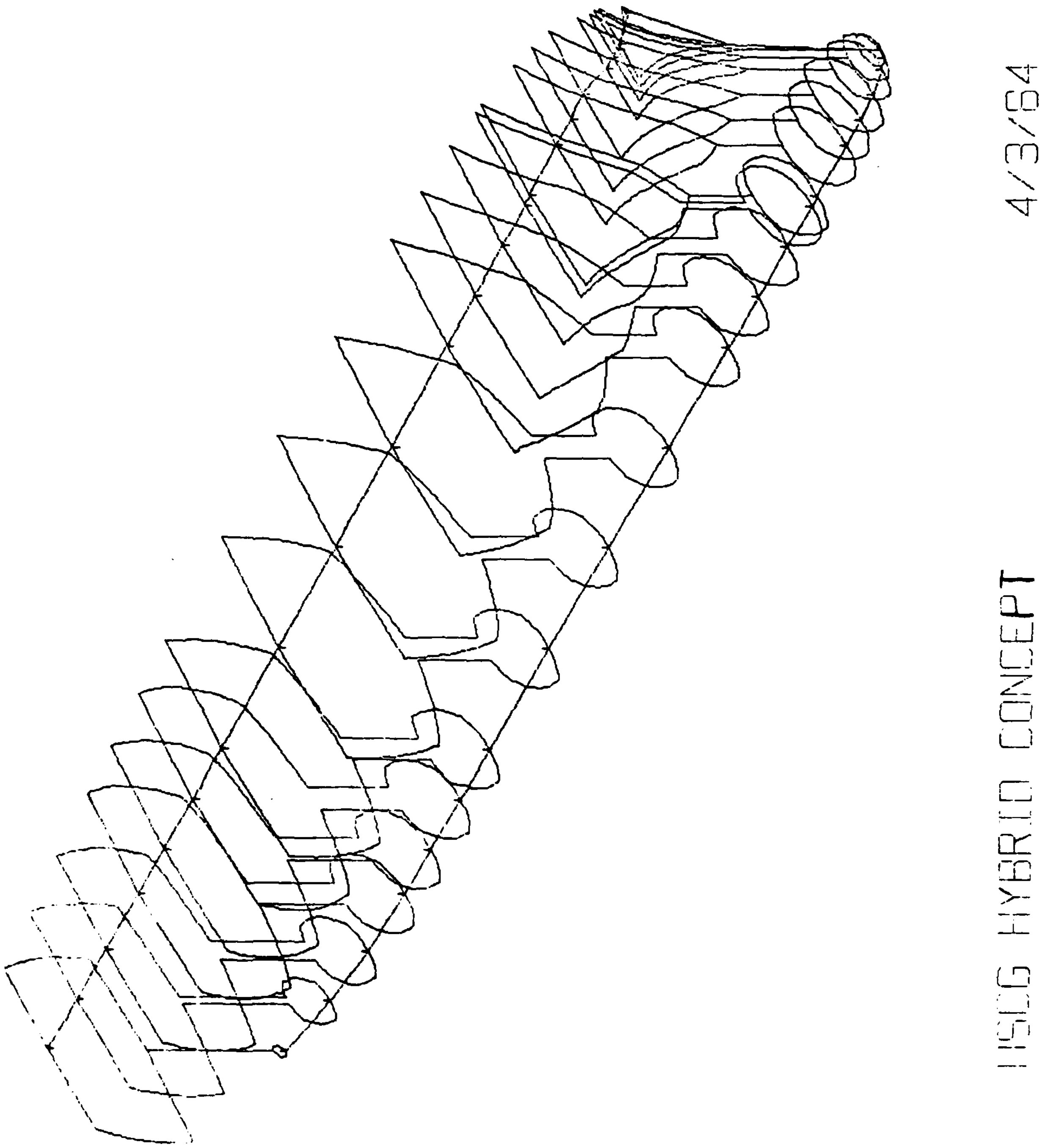


Figure 3-3. USCG HYBRID CONCEPT

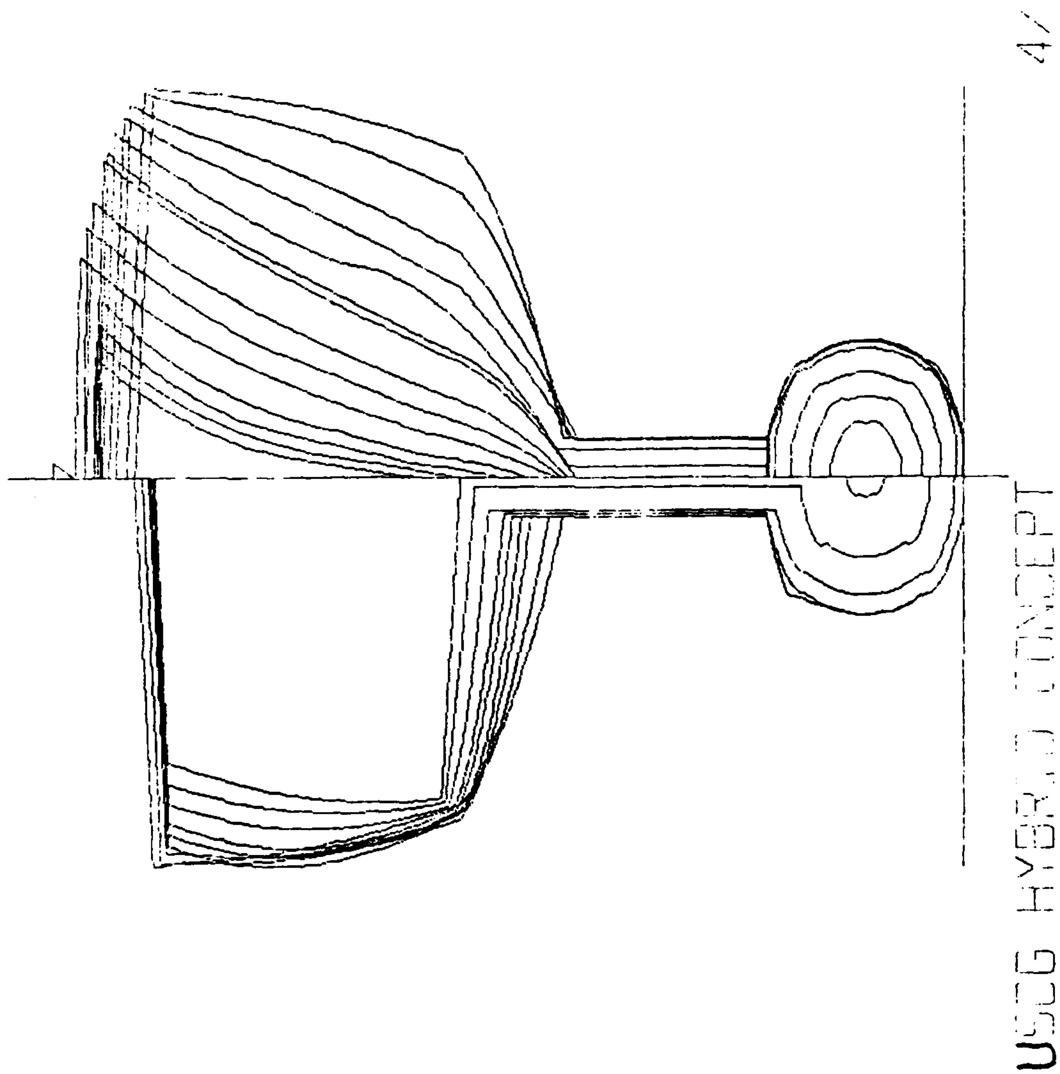


Figure 3-2. USCG HYBRID CONCEPT

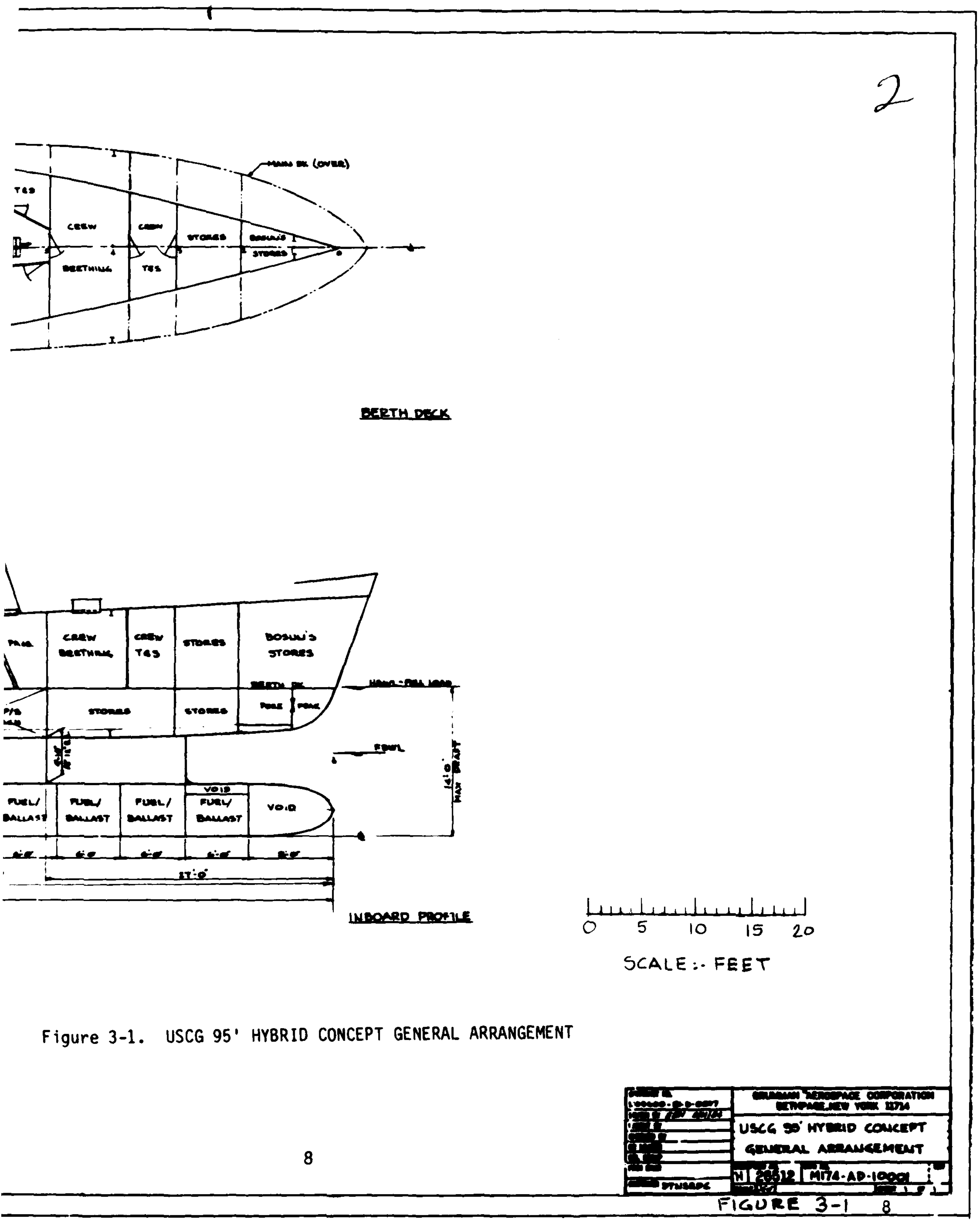


Figure 3-1. USCG 95' HYBRID CONCEPT GENERAL ARRANGEMENT

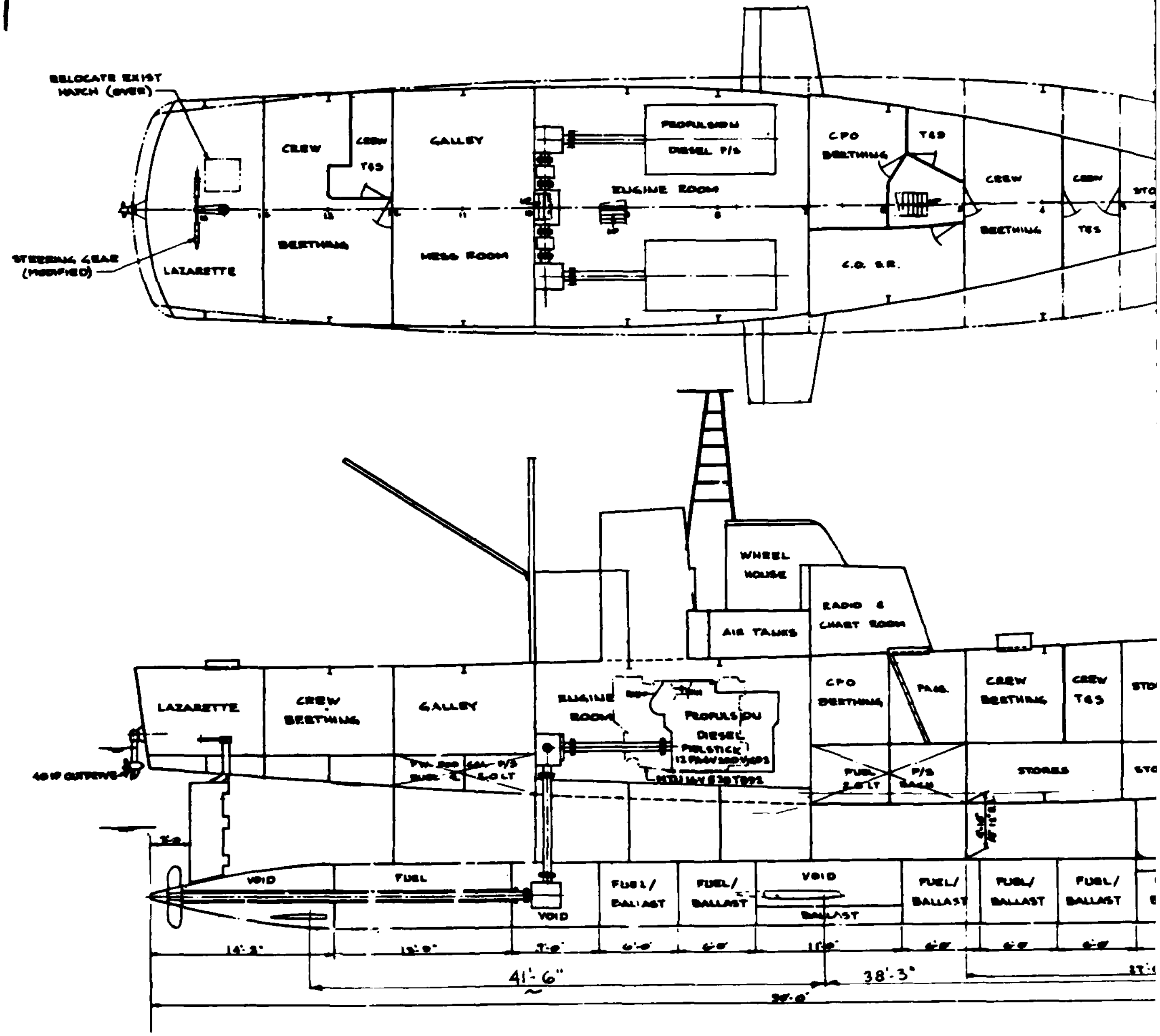


Figure 3-1. USC(

SECTION 3
CRAFT DESCRIPTION

3.0 The 95 ft WPB is a semi-planing displacement craft with the following principal characteristics, exclusive of the buoyancy/fuel tank and strut and foil system:

Length Between Perpendiculars	90'-0
Length Overall	95'-0
Beam (Maximum)	20'-1 1/2"
Beam (At 6'0' WL)	18'-5"
Draft at Full Load	6'-3 1/2"
Displacement - Light Ship	85.98 L.tons
Displacement - Full Load	103.53 L.tons

With the addition of the buoyancy/fuel tank and the foil system to the craft the displacement and draft are altered to the following:

Draft - Maximum Hullborne	14'-1"
Beam Across Foils	30'-0"
Displacement - Light Ship	128.83 L.tons
Displacement - Full Load Ballast	181.33 L.tons

Figure 3-1 illustrates the feasibility configuration investigated.

3.1 For the purpose of investigating hydrodynamics and intact stability, NAVSEA's Ship Hull Characteristics Program (SHCP) was utilized. Inasmuch as the strut and tank become an integral part of the hull, they were treated as such rather than as appendages, and the bottom of the tank became the reference baseline.

The foils were, however, included as appendages inasmuch as the program could not directly handle the foil anhedral.

3.2 To verify the offset inputs graphic plots, Figures 3-2 and 3-3 were generated. The slight irregularities visible are the result either of erroneous inputs or an insufficient number of points to define the curved portion

2.1.4 At a fixed displacement of 181.3 tons, the maximum foilborne endurance is about 53 hours at 22.5 knots, whereas maximum range is 1314 n. miles at 27.5 knots in calm water, both with 10% reserve fuel. Hullborne range is 2600 n. miles at 12.5 knots (4180 n. miles at 10 knots) in calm water with 10% reserve fuel. These values compare with 460 n. miles at 21 knots and 3000 n. miles at 9 knots for the current WPB.

2.1.5 There is adequate fuel (with a 10% reserve) to carry out a 5-day mission of 24 hours at 30 knots, plus 96 hours at 13 knots for a total range of 1968 n. miles.

2.1.6 Intact stability analyses indicates that in the full load condition of 181.3 tons the craft would be stable up to and including 70 knots beam winds. Ballast must replace fuel from the buoyancy/fuel tank periodically as it is burned off under high beam wind conditions.

2.1.7 Motions in a seaway are projected to be greatly improved over that of a planning hull of this size and should compare favorably with a hydrofoil having a fully submerged foil system.

SECTION 2
CONCLUSIONS

2.0 The investigation of the factors involved in the creation of the U.S. Coast Guard Hybrid Concept Design M-174 was resolved primarily into the areas of performance and stability. While not totally complete in such areas as relocation of equipments in the machinery room, the investigation also assessed propulsion options, fuel/ballast management and hull modifications which were to have the most influence on the acceptability of the concept.

Throughout all of the analysis, several ground rules were established which had a direct bearing on the final results. One was the recommendation of the Coast Guard that diesel engines be considered as the prime movers in lieu of gas turbines. Secondly, the hullborne draft was to be a maximum of 14 feet. Thirdly, that payload development for a new WPB be considered in the weight estimate and a specific five-day mission profile be examined.

2.1 Conclusions from the investigation of hybrid concept M174 design, derived from an existing WPB, are as follows:

2.1.1 The hybrid concept is technically feasible, has merit, and provides considerable improvement over that of the WPB particularly in the areas of speed, range and motions. The boat is of all-steel construction and has a full load displacement of 181.3 long tons. In the foilborne mode, dynamic lift is 98.3 tons and buoyant lift is 83 tons. Full load fuel is 38.1 tons (useable) in addition to 15 tons of miscellaneous loads (command and surveillance, crew and effects, stores, water, armament, and lube oil).

2.1.2 Two Pielstick 12PA4200-VGDS diesel engines with a maximum continuous rating of 2960 hp each provide a full load maximum foilborne speed of 34.0 knots in calm water. This compares with 21 knots for the current WPB.

2.1.3 Takeoff thrust margin is about 40% at 20 to 22 knots in the full load condition and therefore is more than adequate compared to most pure hydrofoil designs.

Figure 1-1. U.S. COAST GUARD HYBRID CONCEPT

SECTION 1
INTRODUCTION

1.0 Grumman Aerospace Corporation, Naval Ship Systems Department has conducted this investigation into the feasibility of generating a hybrid surface ship by installing a buoyancy/fuel tank and submerged foil system on an existing USCG 95 ft WPB hull. This investigation is a continuation of the general exploration into the feasibility of enhancing the performance of surface craft by utilizing a combination of dynamic lift provided by a foil system, and buoyant lift provided by a long, slender fully submerged hull and strut. References 1 through 9 describe the previous work on various hybrid ship designs.

1.1 The purpose of the investigation was to determine the technical validity of using a buoyancy/fuel tank and associated foil system to improve performance and enhance mission capabilities of an existing USCG 95 ft WPB.

An existing WPB with nominal 105 L.ton full load displacement was selected by DTNSRDC and the United States Coast Guard as the platform on which to conduct the feasibility investigation. The craft with a buoyancy/fuel tank and foil system attached to the keel is referred to as USCG Hybrid Concept, Grumman Design No. M174, in the sections following. All performance and stability calculations were based upon the 85.98 long ton light ship displacement as developed in the Stability Test Data for WPB 95303, "Cape Upright," dated 10 November 1977. Analyses of the concept are contained in the following sections. A rendering of the concept is shown in Figure 1-1.

ADMINISTRATIVE INFORMATION

The investigation described in this report was performed for the U.S. Coast Guard (MIPR DTCG23-84-F-20024) by the Grumman Aerospace Corporation, Naval Ship Systems Department under Contract N00600-81-D-0877 from the David Taylor Naval Ship Research and Development Center. The Project Manager at DTNSRDC was John R. Meyer, Code 1233, of the Hydrofoil Systems Office. The U.S. Coast Guard project officer was LTJG Ian Grunther.

FOREWORD

Grumman Aerospace Corporation, Naval Ship Systems Department has conducted this investigation into the feasibility of generating a hybrid surface ship by installing a buoyancy/fuel tank and submerged foil system on an existing USCG 95-ft WPB hull as Task 15 of Contract N00600-81-D-0877.

This investigation is a continuation of the general exploration into the feasibility of enhancing the performance of surface craft by utilizing a combination of dynamic lift provided by a foil system, and buoyant lift provided by a long, slender fully submerged hull and strut. See references 1 through 9 for previous efforts.

This report provides a feasibility analysis of the application of a physically well-defined buoyancy/fuel tank and hydrofoil system to a specific craft, an existing USCG 95-ft WPB.

ABSTRACT

This report provides a feasibility analysis of the application of a physically well-defined buoyancy/fuel tank and hydrofoil system to a specific craft, an existing USCG 95-foot WPB. The purpose of this modification is to enhance the craft's mission capabilities in terms of speed, range/endurance and motions in a seaway.

It is concluded that the hybrid concept (Design M174) is technically feasible, has merit, and provides considerable improvement over that of the WPB, particularly in the areas of speed, range and motions. The 181.3 long ton design is all steel, has 2 Pielstick diesel engines and carries 38.1 tons of usable fuel in addition to a mission load of 15 tons. Full load maximum speed is 34.0 knots, maximum foilborne endurance is 53 hours at 22.5 knots, and maximum range is 1314 n. miles at 27.5 knots. Hullborne range at 12.5 knots is 2594 n. miles. There is adequate fuel (with a 10% reserve) to carry out a 5-day mission of 24 hours at 30 knots, plus 96 hours at 13 knots for a total range of 1968 n. miles.

Additional studies are required in conjunction with a detailed design of such a demonstrator. It is recommended that a new design (similar to M174) be investigated in which the upper hull would be modified to improve intact stability, overall structural efficiency, and the machinery room layout. Also, an optimum propeller should be designed to accommodate the entire foilborne speed regime.

4.1 Foil System Characteristics

4.1.1 Airplane Configuration Characteristics

The airplane configuration consists of a main foil (~75% of dynamic lift) located near midship and a tail foil (~25% of lift) located aft. Foil planforms and geometric characteristics are shown on Figures 4.1.1-1 and -2. The main foil aspect ratio and relatively large portion of foil enclosed by the pod are both rather extreme for a hydrofoil and result from the large tank width and constrained foil span. All of the lift and induced drag characteristics of this report were derived by the methods of reference 10. The lift characteristics are based upon potential flow theory. At this study level it was not necessary to specify a foil section, and the viscous lift effects are not considered to be consequential to feasibility conclusions.

The main foil spanwise circulation distribution is shown on Figure 4.1.1-3 where the pitch lift curve slope, C_{L_α} describes the lift obtained when the craft is pitched while the incidence lift curve slope, C_{L_i}, describes the lift obtained when the foil incidence changes relative to the tank. The incidence and flap lift curve slopes differ only by the value of the flap effectiveness $d\alpha/ds$. The main foil C_{L_i}/C_{L_α} ratio, .7, is low for hydrofoils because so much of the span is fixed but flap angle requirements to 20 knots do not exceed 15 degrees for a 25% chord flap. The incidence lift case is sometimes approximated by joining the exposed semi-spans to make a new foil without a pod as shown on Figure 4.1.1-3 but that approximation is poor for this case because of the large fixed span extent.

The main foil spanwise lift coefficient distribution is shown on Figure 4.1.1-4 where the maximum incidence lift C_ℓ/C_L, ratio of 1.34 compares with a more typical value of 1.25. Foil cavitation is initiated at this section of highest local lift coefficient.

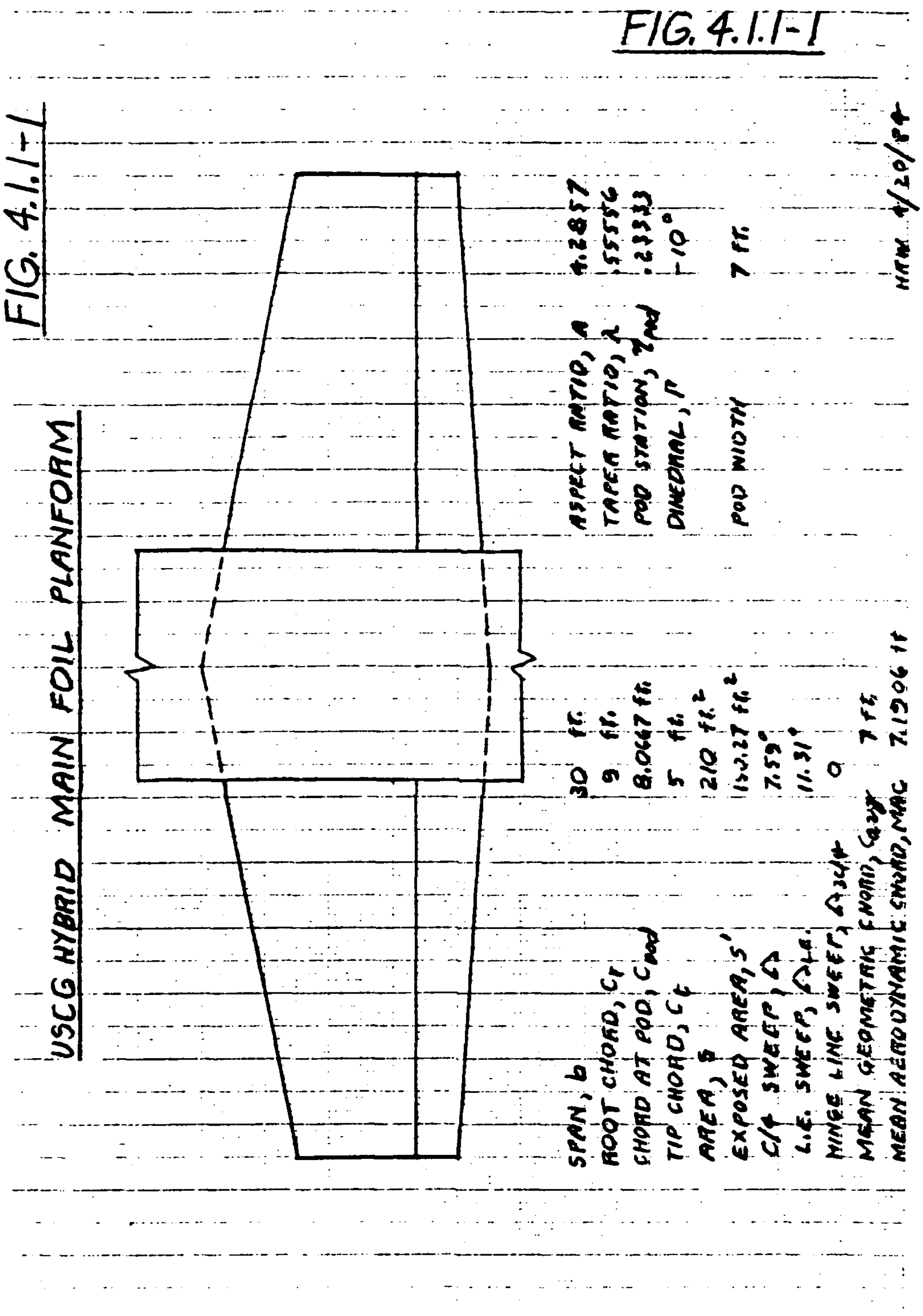


Figure 4.1.1-1. USCG HYBRID MAIN FOIL PLANFORM

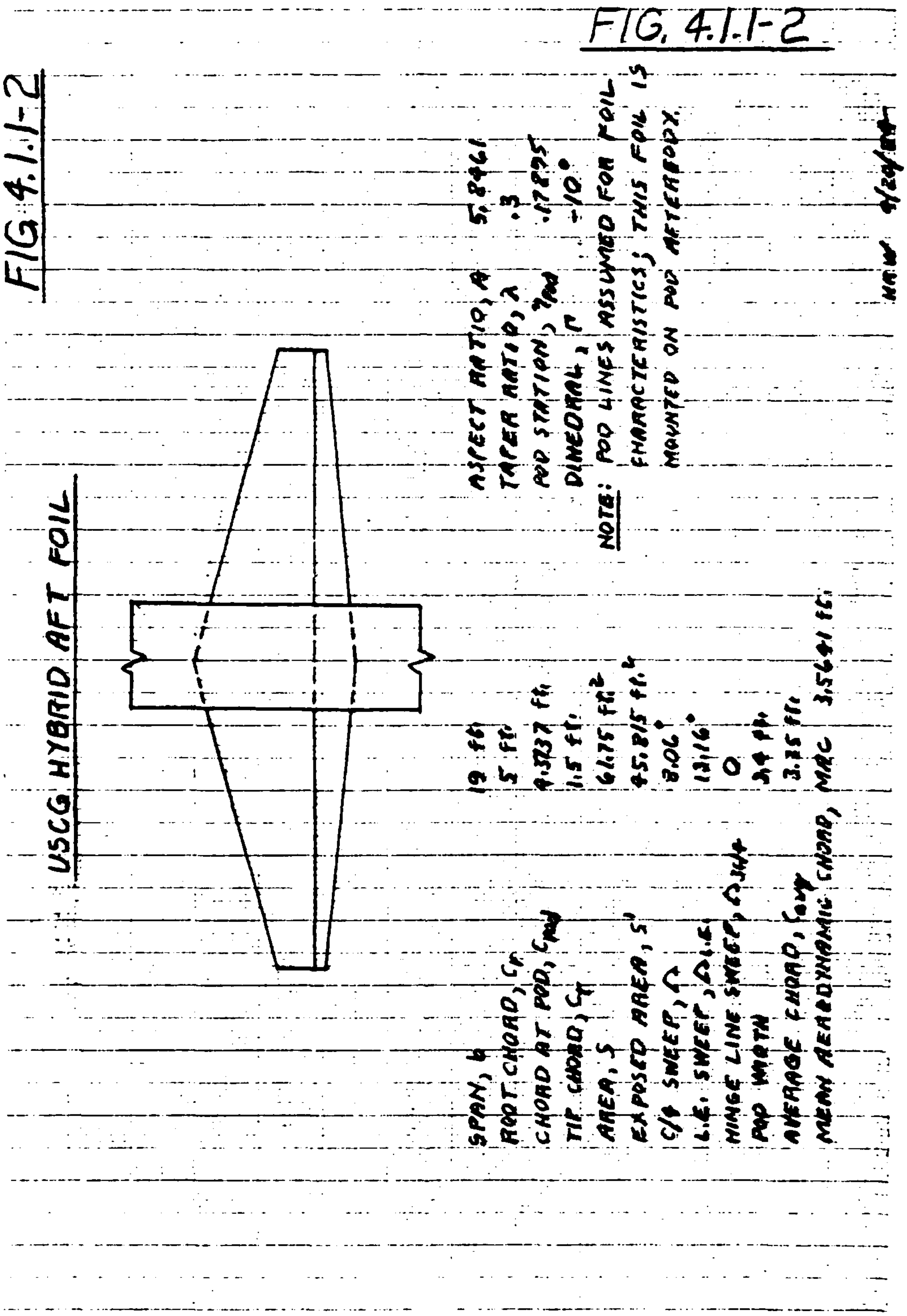


Figure 4.1.1-2. USCG HYBRID AFT FOIL

FIG. 4.1.1-3

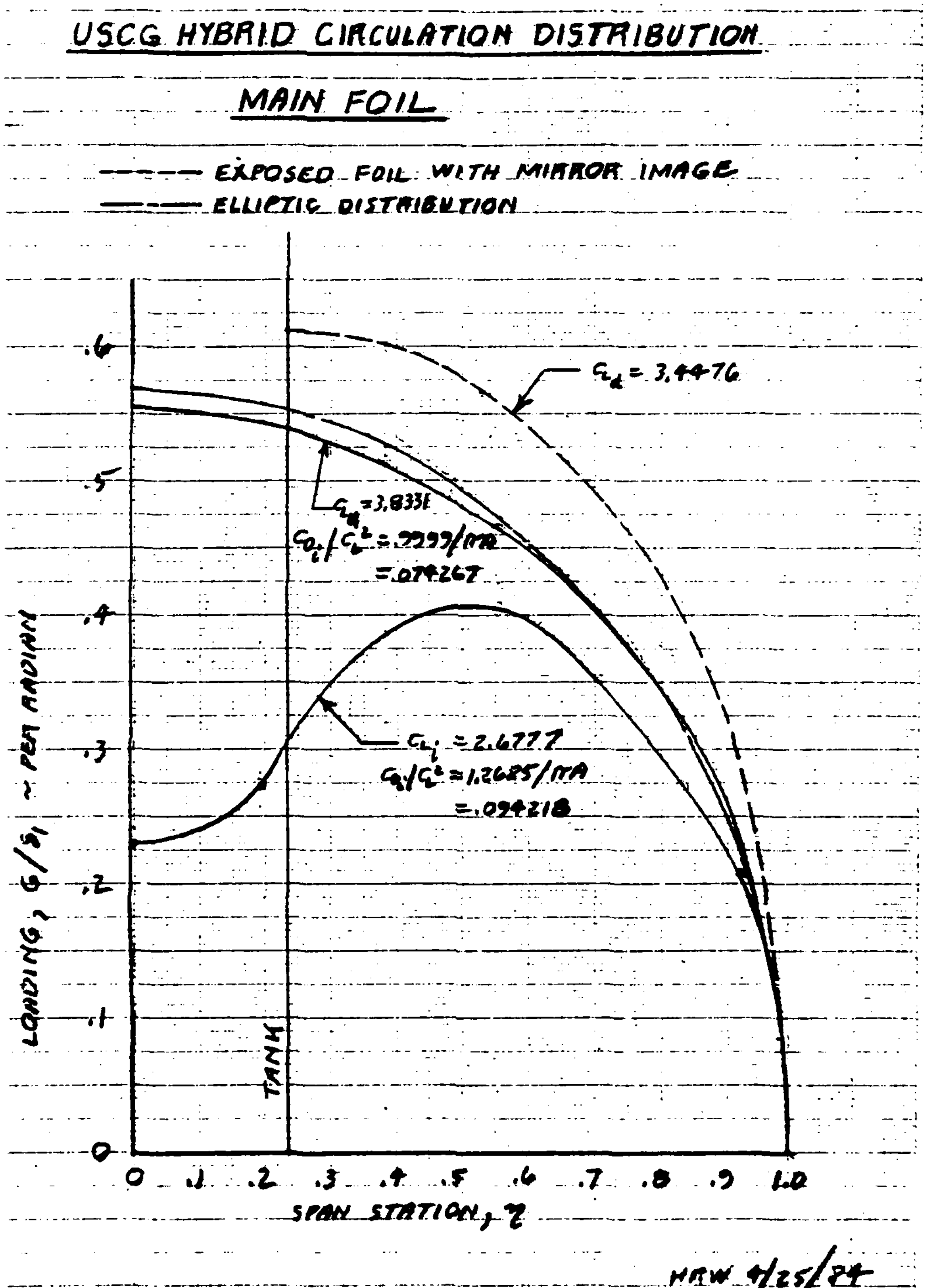


Figure 4.1.1-3. USCG HYBRID CIRCULATION DISTRIBUTION MAIN FOIL

FIG 4.1.1-4

USCG HYBRID LIFT COEFFICIENT DISTRIBUTION

MAIN FOIL

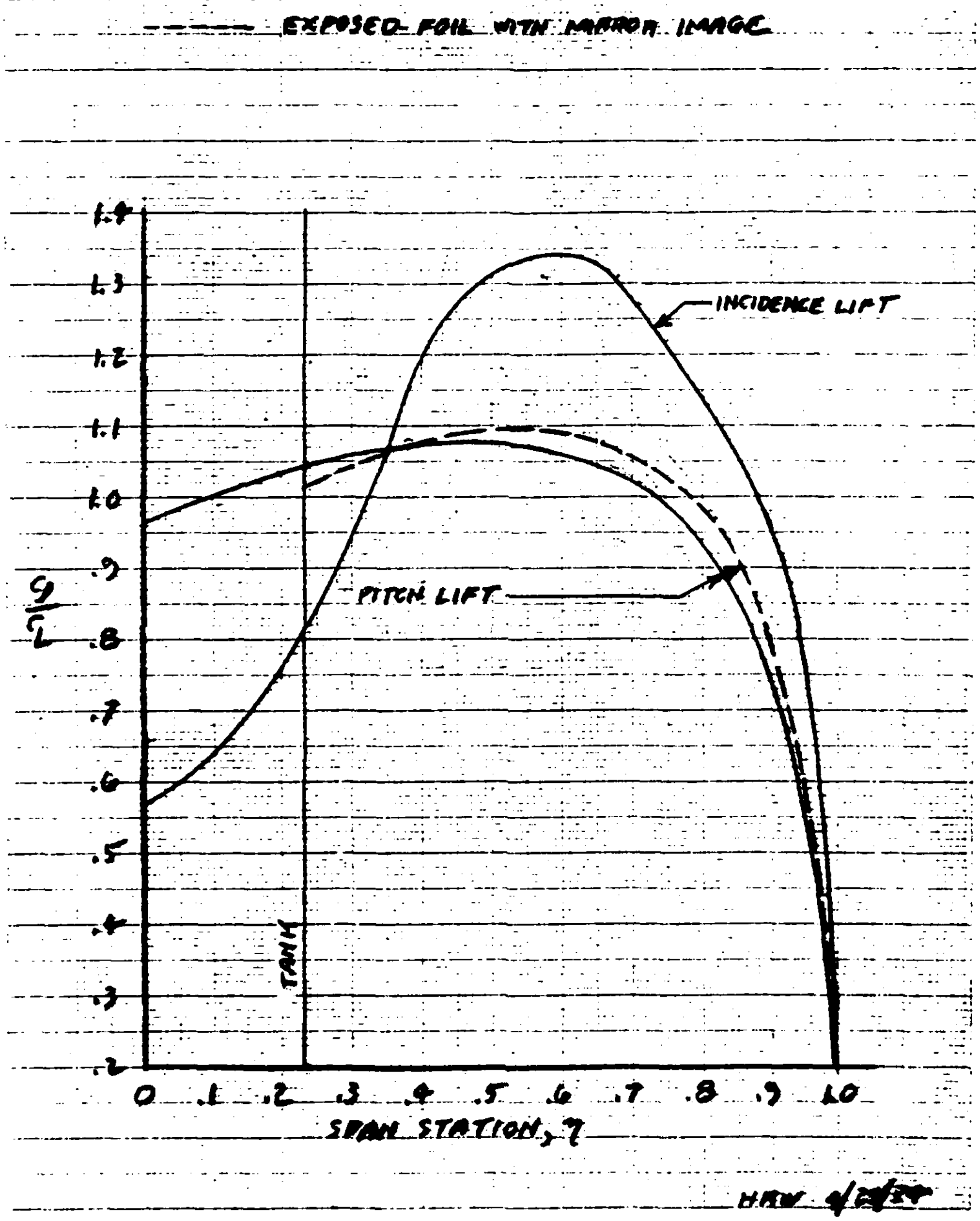


Figure 4.1.1-4. USCG HYBRID LIFT COEFFICIENT DISTRIBUTION MAIN FOIL

The performance characteristics for the main foil are summarized in Table 4.1.1 where they are compared with the characteristics of two alternate foil systems. The 20 knot speed was the lowest speed of immediate interest but the drag curve indicates that the minimum flight speed might be as low as 15 knots and effective foil control throughout the flight speed envelope would be desirable.

Time did not permit derivation of the asymmetric, aileron, circulation distribution which is more unfavorable than that for symmetric flap deflection. A detail design phase would have to consider the roll control and orbital motion requirements along with the alleviating effect of craft pitch at low speed and in turns.

The aft foil characteristics were assumed identical with those of the forward foil to conserve time, although this assumption provides conservative craft characteristics.

4.1.2 Tandem Configuration Characteristics

The disadvantages of the main foil can be alleviated to some extent by increasing the foil area but to accomplish this with a reasonable aspect ratio within a constrained span requires resort to a tandem configuration.

Figure 4.1.2-1 presents one possibility for a tandem foil system and Figure 4.1.2-2 presents the corresponding circulation distribution. The lift coefficient distribution for this more highly tapered foil, Figure 4.1.2-3, is worse than that of Figure 4.1.1-4.

The characteristics for this foil and for a similar rectangular version are compared with those for the main foil in Table 4.1.1. The foil of Figure 4.1.2-1 adds about 1/2 knot to the top speed but the top speed certainly presents a limit to the foil area which can be added. Obviously an optimized tandem foil system would require area and taper consideration and would still present the craft dynamics disadvantages which have been found associated with the tandem system for this application in reference 2.

Table 4.1.1

FOIL SYSTEM CHARACTERISTICS

Foil System	Aspect Ratio A	Taper Ratio λ	C/4 Sweep Λ deg.	Foil Lift LT long tons	Foil Area S ft.^{2}	Foil Loading L/S PSF	Lift Coeff C_L		Max. $(C_\ell/C_L)_i$	Max. $(C_\ell)_i$ (1)		Flap Angle δ degrees (2)		$\pi A \frac{C_{D_i}}{(C_L)_i^2}$ (3)	C_{D_i}/C_L^2	$C_{D_i}/C_L^2 \cdot L_T^2/S$ (4)
							20 Kts.	15 Kts.		20 Kts.	15 Kts.	20 Kts.	15 Kts.			
Airplane Config. Main Foil	4.286	.5556	7.59	59.4	210	634	.5584	.9926	1.34	.748	1.33	15.0	32.4	1.268	.09422	1.58
Tandem Config. Tapered	6	.3	10.17	38.1	150	569	.5011	.8909	1.45	.726	1.29	12.1	26.0	1.315	.06977	.67
Tandem Config. Rect.	6	1	0	38.1	150	569	.5011	.8909	1.39	.697	1.24	12.0	25.8	1.44	.07639	.74

NOTES:

1. Cavitation initiation is at section of maximum C_ℓ
2. For 25% chord flap
3. $\pi A C_{D_i}/C_L^2 = 1$ for elliptic circulation distribution
4. $D_i = \frac{(2240)^2}{q} \cdot \frac{C_{D_i}}{C_L^2} \cdot \frac{L_T^2}{S}$

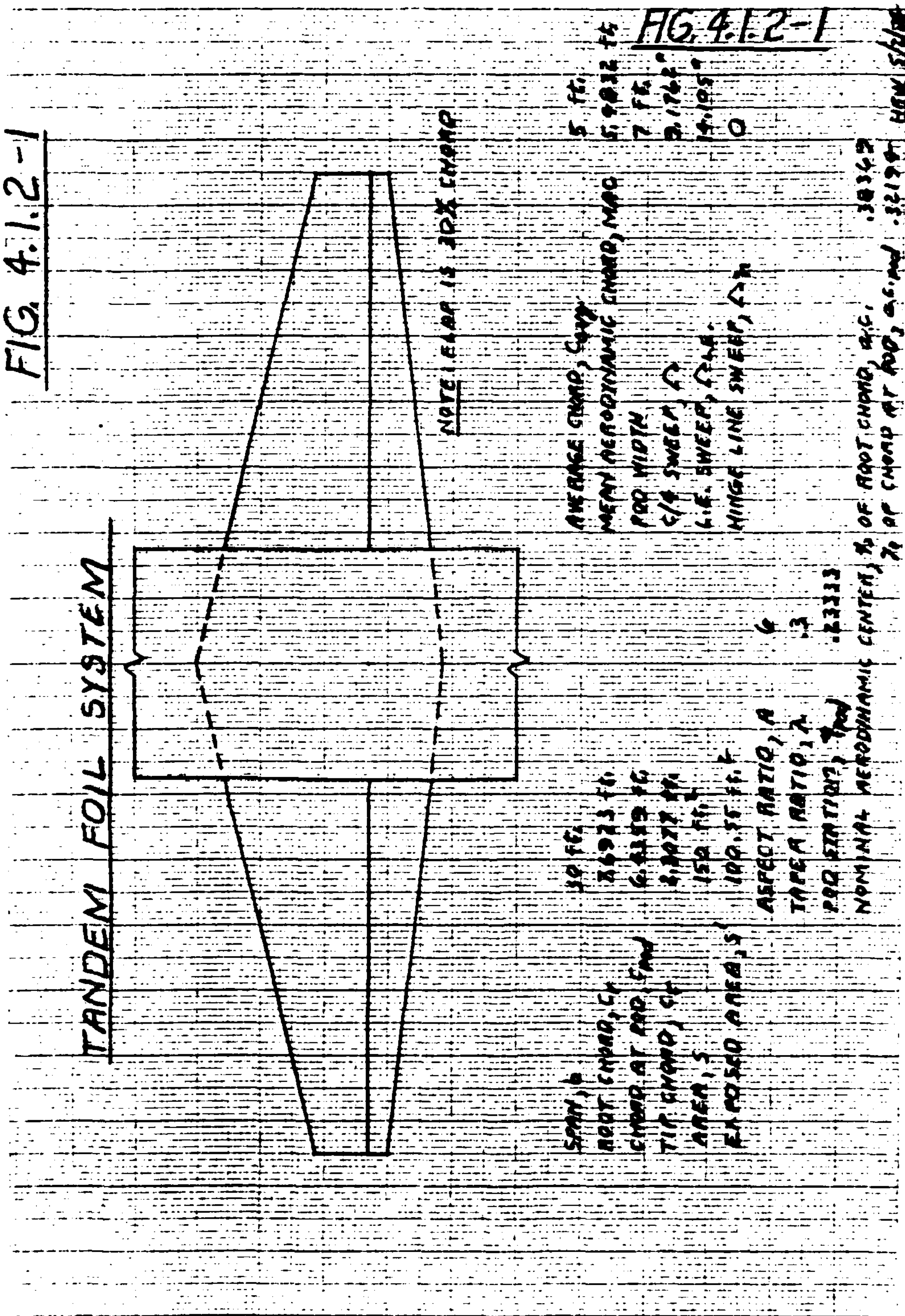


Figure 4.1.2-1. TANDEM FOIL SYSTEM

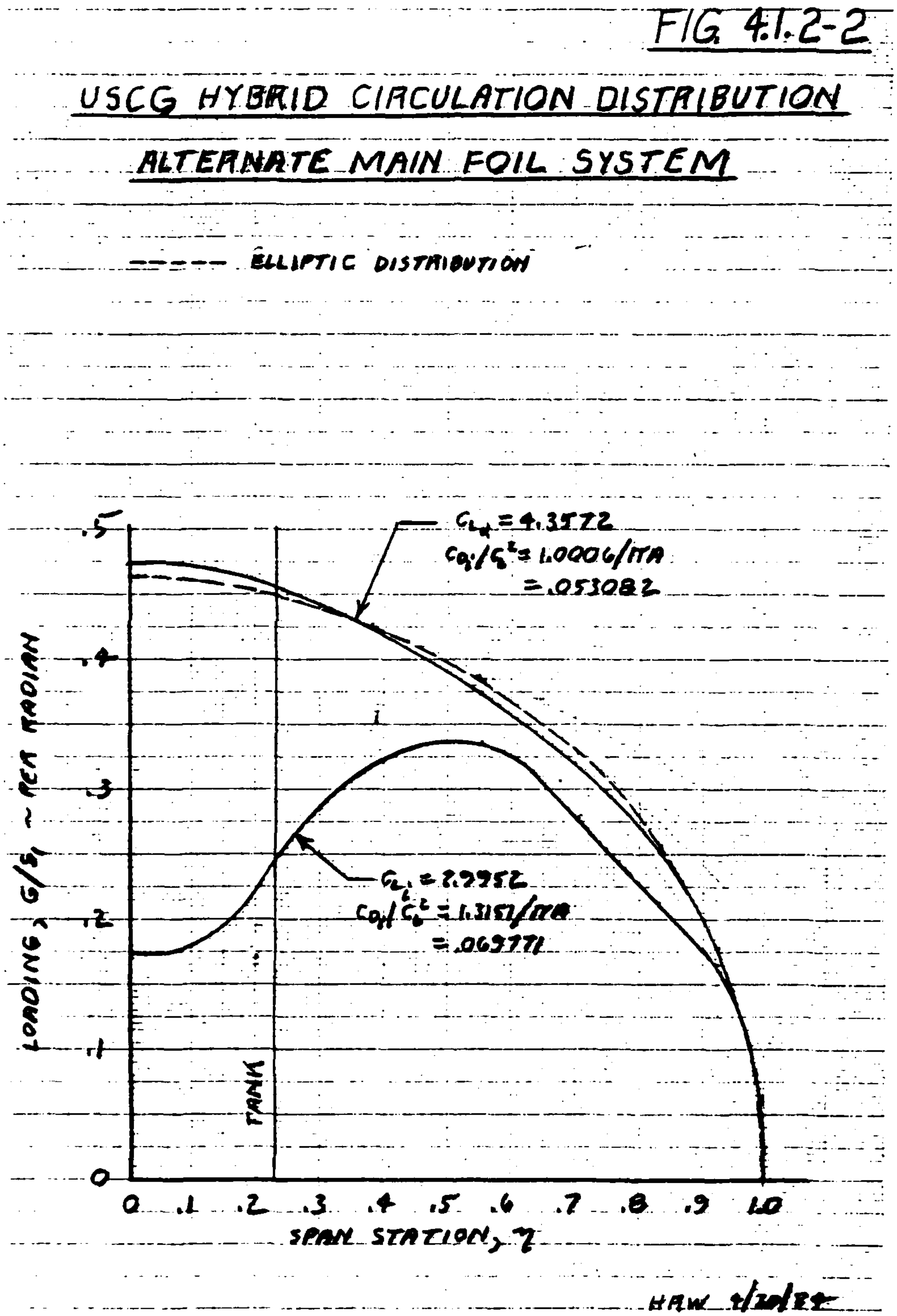


Figure 4.1.2-2. USCG HYBRID CIRCULATION DISTRIBUTION ALTERNATE MAIN FOIL SYSTEM

FIG. 4.1.2-3

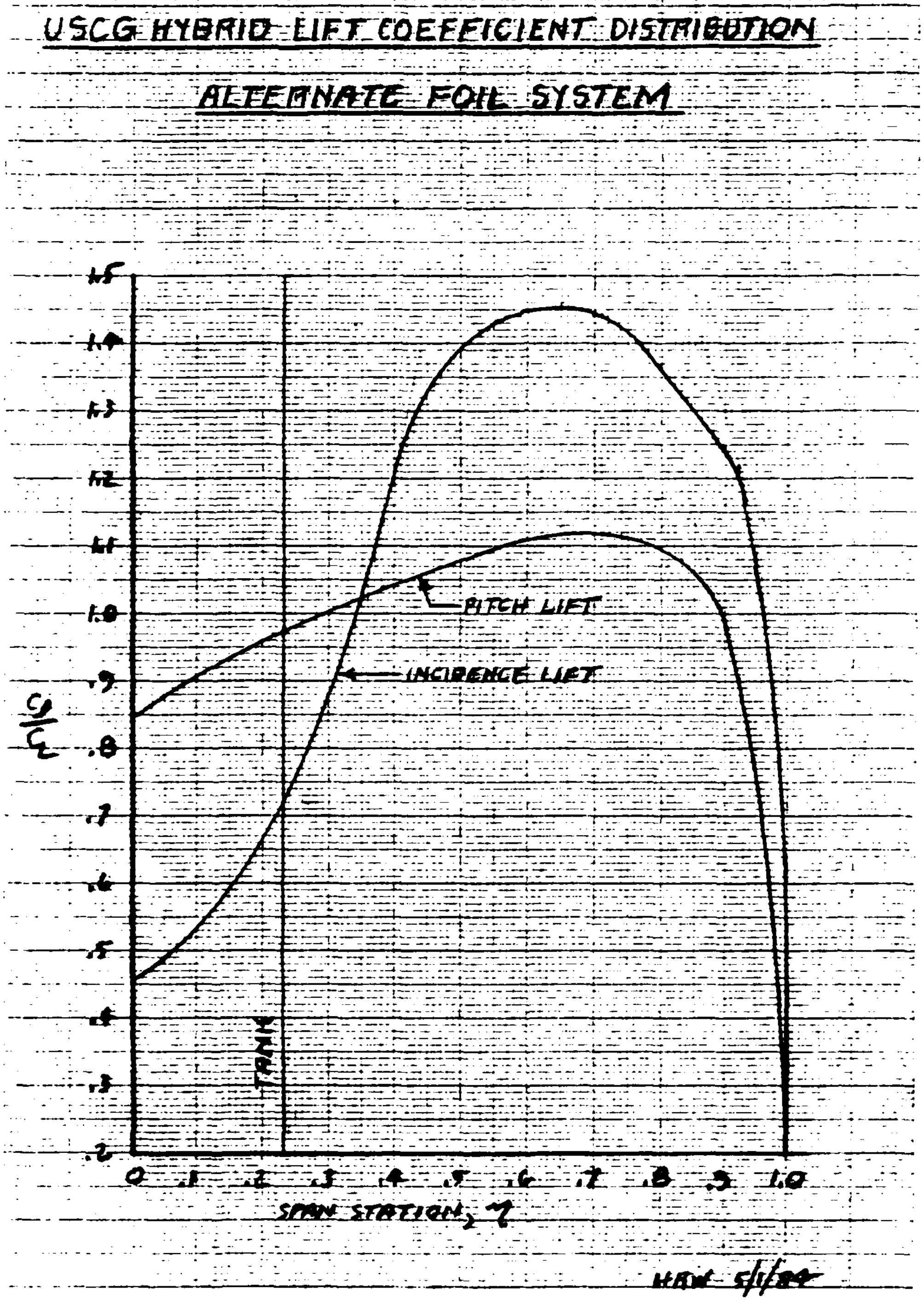


Figure 4.1.2-3. USCG HYBRID LIFT COEFFICIENT DISTRIBUTION ALTERNATE FOIL SYSTEM

Note that the tandem foil system does allow employment of the total foil area in roll control.

4.2 Craft Drag Polar

4.2.1 Derivation of the Craft Drag Polar

The submerged parasite drags were estimated in the manner of reference 7 and 11 for comparison with the DTNSRDC supplied drag curve as shown on Figure 4.2.1-1. The estimated spray and air drags were then added to the DTNSRDC drag curve to obtain the total parasite drag curve.

The calculated parasite drag coefficients are fit to a quadratic in 1/q on Figure 4.2.1-2 and the result is compared with the drag calculations on Figure 4.2.1-1. For a craft foil loading of:

$$\frac{L}{S} = \frac{2240 \times 76.2}{271.75} = 628.11 \qquad 4.2.1\text{-}1$$

the resulting parasite drag polar is:

$$C_{D_P} = .02497 + 29.114 \frac{1}{q} - 10821 \left(\frac{1}{q}\right)^2 \qquad 4.2.1\text{-}2$$

$$= .02497 + \frac{29.114}{628.11} C_L - \frac{10821}{(628.11)^2} C_L^2$$

$$= .02497 + .046352 \ C_L - .027428 \ C_L^2$$

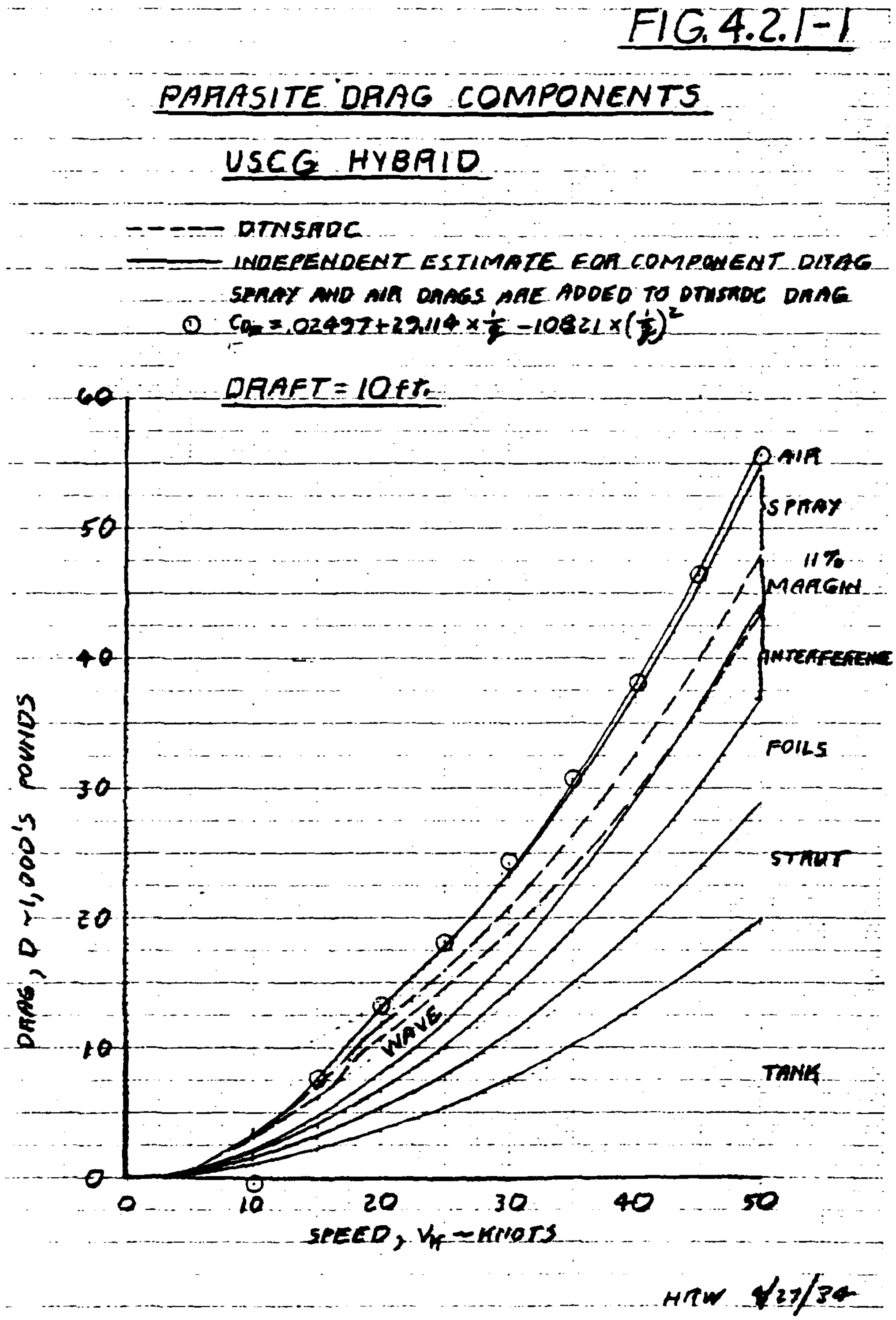


Figure 4.2.1-1. PARASITE DRAG COMPONENTS USCG HYBRID

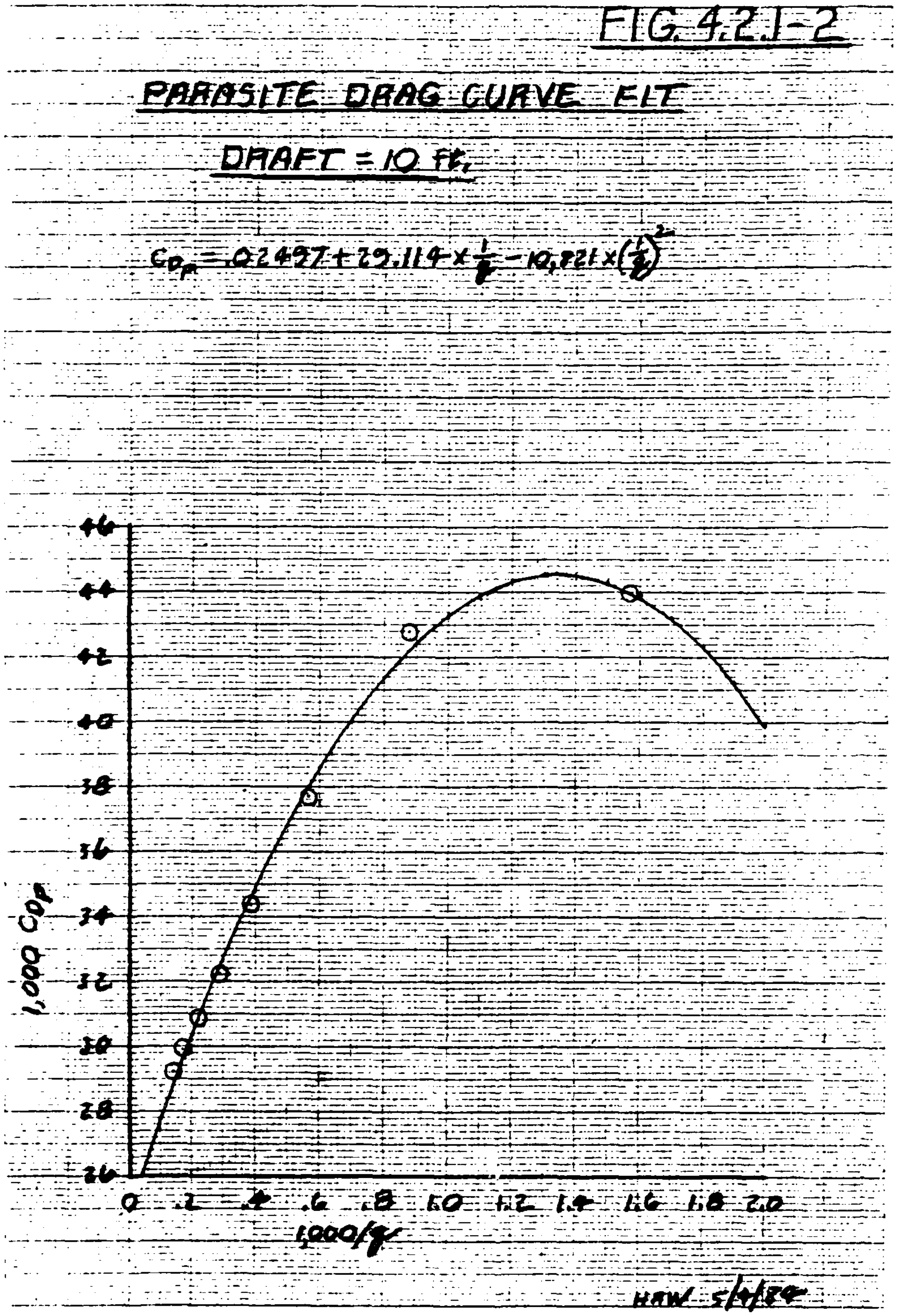


Figure 4.2.1-2. PARASITE DRAG CURVE FIT DRAFT = 10 FT.

By the methods of reference 11 the induced and surface image drag coefficients are:

$$C_{D_i} = .088647\ C_L^2 \qquad 4.2.1\text{-}3$$

$$C_{D_{SURF}} = .016624\ C_L^2 \qquad 4.2.1\text{-}4$$

where a $\pi A\ C_{D_i}/C_L^2$ of 1.25 was arbitrarily employed for the aft foil in the absence of a circulation distribution analysis.

For design lift coefficients set equal to the foil lift coefficient at 35 knots the wake drag coefficient becomes:

$$C_{D_{WAKE}} = .026091 \left[\frac{(\ell_2/\ell)^2}{S_1/S} + \frac{(\ell_1/\ell)^2}{S_2/S} \right] (C_L - C_{L_{35}})^2 \qquad 4.2.1\text{-}5$$

$$= .026091 \times 1.0003\ (C_L - .18062)^2$$

$$= .026099\ (C_L - .18062)^2$$

The coefficient should be .0035471 for speeds higher than 35 knots but the difference is negligible for the speed range of interest here.

The wave drag coefficients calculated by the methods of reference 11 are fitted to a quadratic in craft lift coefficient on Figure 4.2.1-3 with the result:

$$C_{D_{WAKE}}/\sigma_i = .0013105 - .019255\ C_L + .086962\ C_L^2 \qquad 4.2.1\text{-}6$$

for $L = 76.2$ LT

The propeller efficiency variation with speed is shown on Figure 4.3.2-2. It will be noted that the propeller design point lies outside the speed range. Increasing the propeller diameter would therefore improve the low speed range and endurance and the takeoff efficiency by some significant amount.

The RPM variations with speed are shown on Figure 4.3.2-3.

4.3.3 Range and Endurance

The specific fuel consumption was taken from reference 14 and is shown here on Figure 4.3.3-1. It should be noted, however, that in the flight speed power range (50%-100% of rated power) the MTU SFC's are 4%-5% higher than those of Figure 4.3.3-1.

The specific endurance is given by:

$$E_s = 2240/(SFC\ SHP + SSF) \quad \text{hrs/L.ton} \qquad 4.3.3\text{-}1$$

where: $SFC = .39805 - .020344 \frac{SHP}{1000} + .0026505 \left(\frac{SHP}{1000}\right)^2$

$2368 \leq SHP \leq 5922$

SHP = Total SHP, 2 engines

SSF = ship's service fuel flow = 33 lbs/hr

The variation of specific endurance with speed is shown on Figure 4.3.3-2 which indicates maximum endurances of 1.54 hours/ton at 22.5 knots for the 181.33 ton displacement and 2.196 hours/ton at 20 knots for the 159.3 ton displacement.

The specific range is given by:

$$R_S = V_K E_S \qquad 4.3.3\text{-}2$$

The variation of specific range with speed is shown on Figure 4.3.3-3 which indicates maximums of 38.3 nautical miles/ton at 27.5 knots for the 181.33 ton displacement and 48.55 nautical miles/ton at 25 knots for the 159.3 ton displacement.

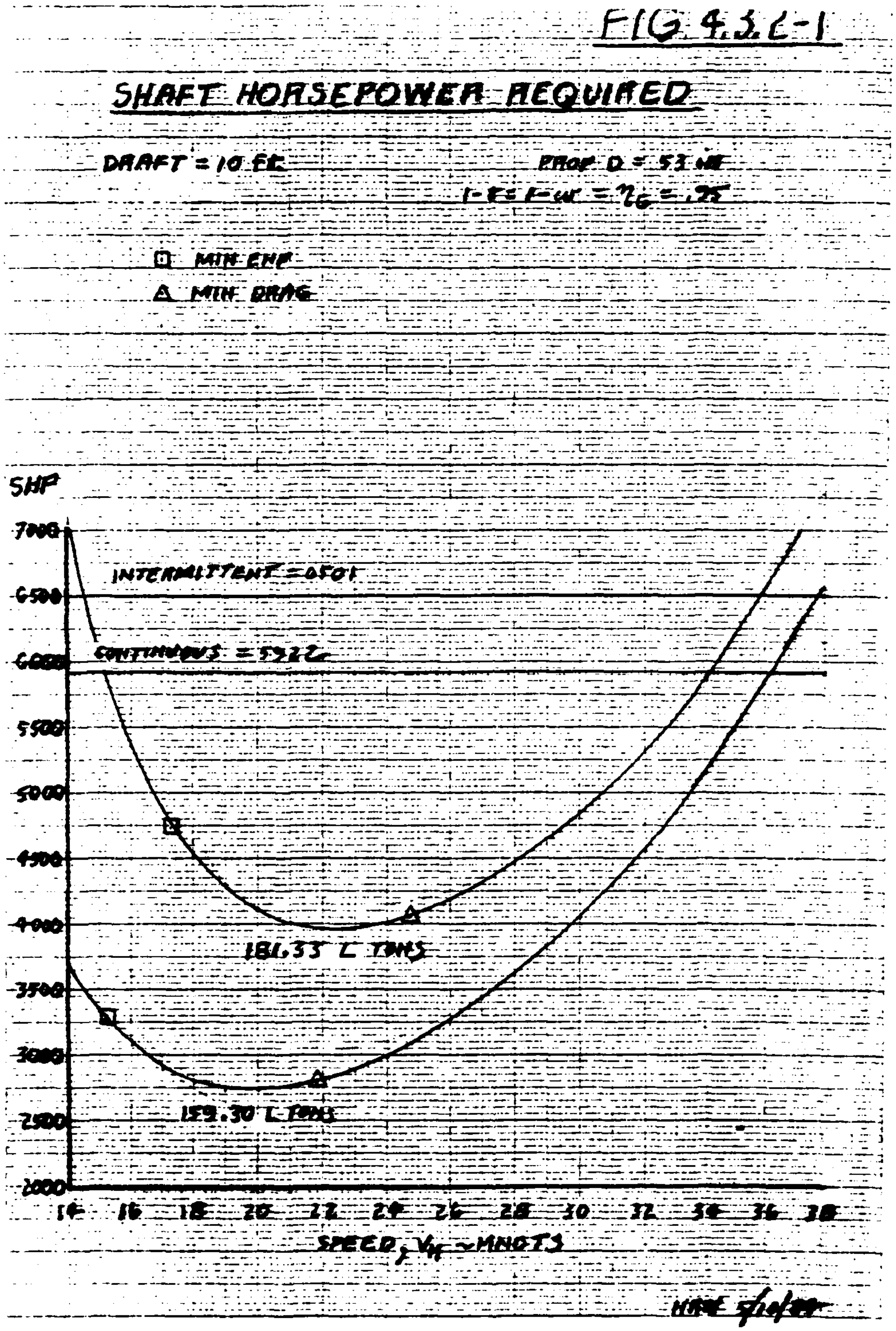


Figure 4.3.2-1. SHAFT HORSEPOWER REQUIRED

4.3.2 Power Required

On the craft drag curve the propeller characteristics are given by the following relationships:

$$C_T = 26.818 \frac{D}{1000} / V_K^2 \qquad 4.3.2\text{-}1$$

or

$$C_T = \frac{S/A}{(1 - \tau)(1 - \omega)^2} C_D = 20.688\ C_D \qquad 4.3.2\text{-}2$$

$$C_P = \left[\frac{1}{2\left(\sqrt{1 + C_T} - 1\right)} + .18097 \right] C_T^2 + .0932 \qquad 4.3.2\text{-}3$$

The speed-power coefficient, C_S, is the solution for:

$$\frac{\pi}{8} C_P C_S^3 = (.875 - .13088\ C_S)^2 \qquad 4.3.2\text{-}4$$

Then:

$$J = .875\ C_S - .13088\ C_S^2 \qquad 4.3.2\text{-}5$$

The SHP required, efficiency, and RPM follow from the evaluations of Table 4.3.1.

For the full throttle case:

$C_P = 8.2967\ \text{SHP}/V_K^3$ 4.3.2-6

C is the solution for Equation 4.3.2-3

C is the solution for Equation 4.3.2-4

is given by Equation 4.3.2-5

The thrust, efficiency, and RPM follow from the evaluations of Table 4.3.1.

The drag and performance calculations were carried out for displacements of 159.30 long tons, (approximate half-fuel weight case) and 181.33 long tons. The power required curves are shown on Figure 4.3.2-1 which provides the maximum speeds of Section 4.0. The minimum flight speed has been increased 4-5 knots by the propeller efficiency curve.

Table 4.3.1

PROPELLER PARAMETERS

Propeller Parameter	Definition	Relationship With Other Parameters	Relationship With System	Evaluation
Power Coefficient, C_P	$\frac{550\eta_G}{(1-w)^3} \cdot \frac{SHP}{\rho AV}$	$\frac{8}{\pi}\frac{J^2}{C_s^5} = C_T/\eta$	$16\ \frac{K_Q}{J^3}$	$8.2967\ \frac{SHP}{V_M^3}$
Thrust Coefficient, C_T	$\frac{1}{(1-w)^2}\ \frac{T}{\rho A}$	$\frac{8}{\pi}\frac{J^2}{C_s^5}\eta = C_P\eta$	$\frac{8}{\pi}\ \frac{K_T}{J^2}$	$26.818\ \frac{D/1000}{V_K^2}$ *
Propeller Efficiency,	$\frac{1-w}{550\eta_G}\ \frac{TV}{SHP}$	$\frac{\pi}{8}\frac{C_T C_s^5}{J^2} = \frac{C_T}{C_P}$	η	$\frac{C_T}{C_P} = 3.2323\ \frac{V_K D/1000}{SHP}$
Advance Ratio, J	$(1-w)\ \frac{V}{\pi D}$	$\frac{\pi}{8}\frac{C_T C_s^5}{\eta})^{1/2}$	J	$21.796\ \frac{V_K}{N}$
Speed-Power Coefficient, C_S	$(1-w)\left(\frac{\rho}{550\eta_G SHP\, N^2}\right)^{1/5} V_K$	$\left(\frac{8}{\pi}\ \frac{J^2}{C_T}\eta\right)^{1/5}$	$J/(2\pi K_Q)^{1/5}$	$2.7087\, V_K/(SHP\, N^2)^{1/5}$

D = 53 inches = 4.4167 ft.
A = 15.321 ft².
$1-w = 1-t = \eta_G = .95$

* T = D/(1-t) in steady-state flight

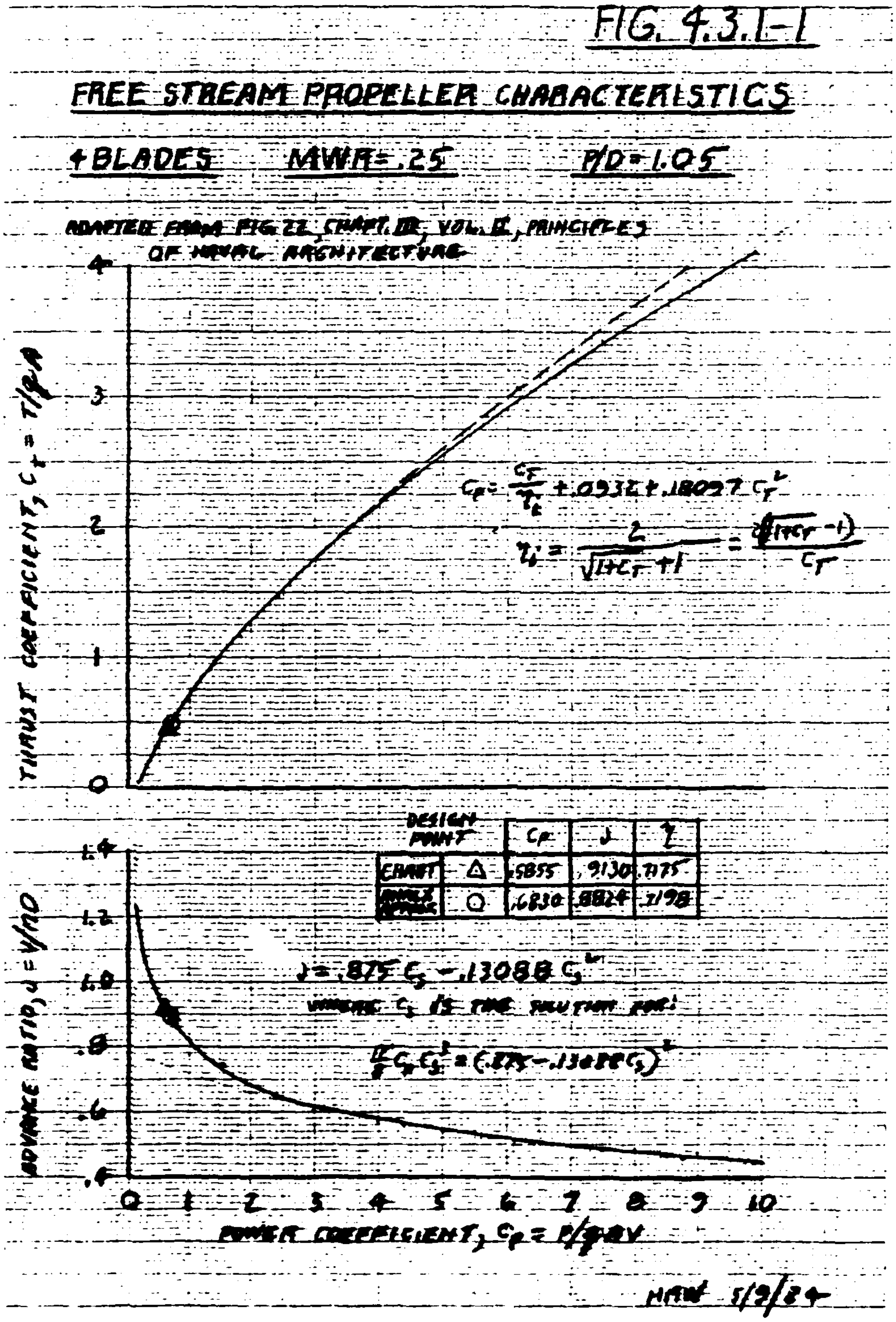


Figure 4.3.1-1. FREE STREAM PROPELLER CHARACTERISTICS

4.3 Craft Performance

4.3.1 Propeller Characteristics

The propeller characteristics employed were taken from Reference 13 and are presented on Figure 4.3.1-1 in a form suited to craft performance analysis. It should be noted that throughout this report the symbol "V" is reserved for craft speed and the propeller operating conditions are:

Prop. Velocity = (1-w) V = .95V

Net Prop. Thrust = (1-t) T = .95T 4.3.1-1

Prop. Horsepower, PHP = η_GSHP = .95SHP

For this preliminary view of the performance, the propeller diameter was set at 53 inches. Increasing this diameter will improve the 20 knot range and endurance to an extent subject to practical limitations. The numerical evaluation for the propeller parameters for the 53 inch diameter are given in Table 4.3.1.

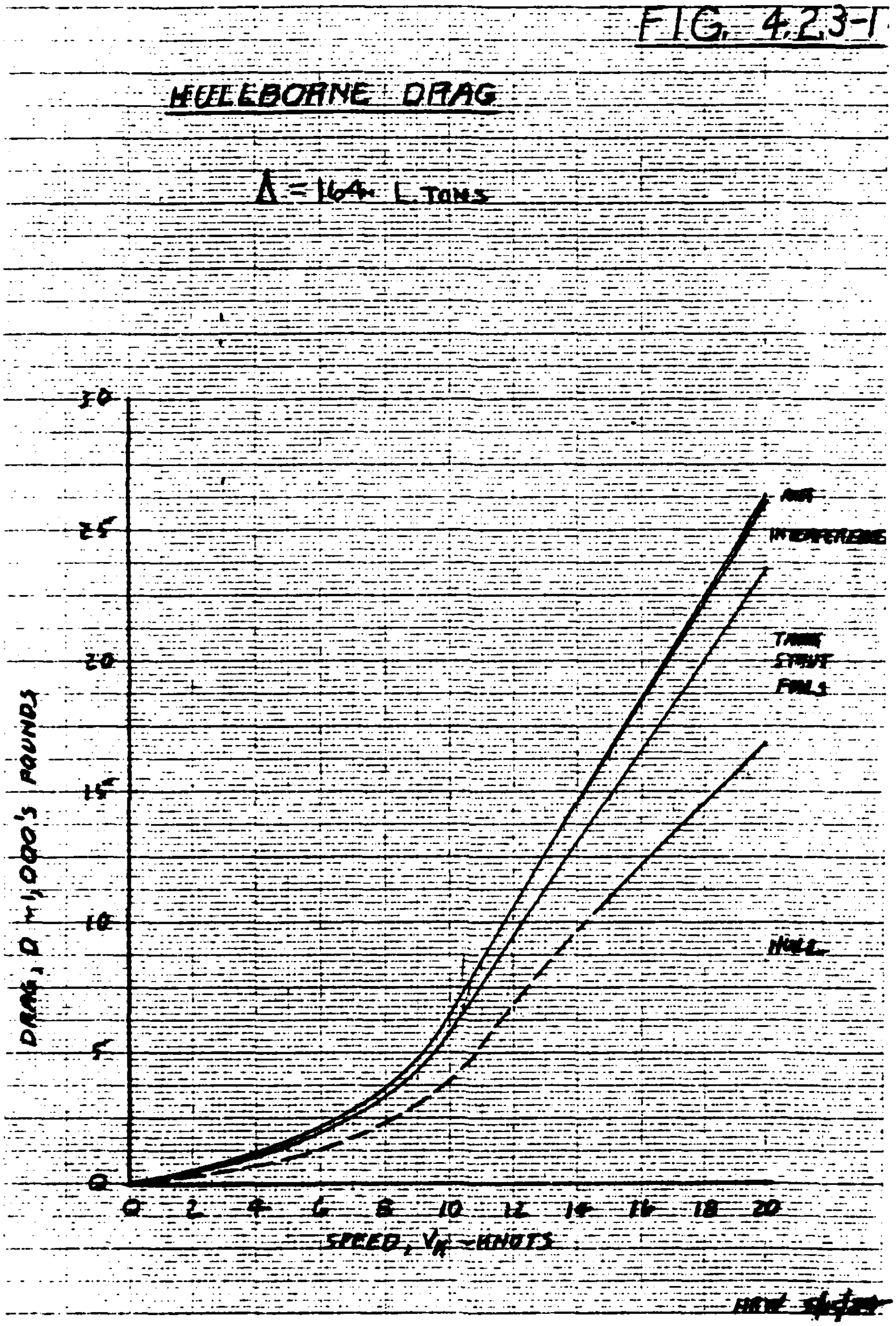


Figure 4.2.3-1. HULLBORNE DRAG

4.2.2 Rough Water Drag

Because the drag curves of Figure 4.2.1-6 assume a fully wetted strut they can be considered conservative in sea states of significant wave height of one meter or less. Drag increments with increasing sea state are due to intermittent hull spray and wave action on the tank, neither of which is amenable to analysis. Time available to this study does not allow review of experimental results on similar configurations for the estimation of these effects.

4.2.3 Hullborne Drag

The hullborne drag curve of Figure 4.2.3-1 adds the parasite drags of Section 4.2.1 to the hull model drag of reference 12. It should be noted that the hull model drag has been extrapolated below 14.5 knots. Extension of the model measurements to lower speeds would be desirable in a detail design phase.

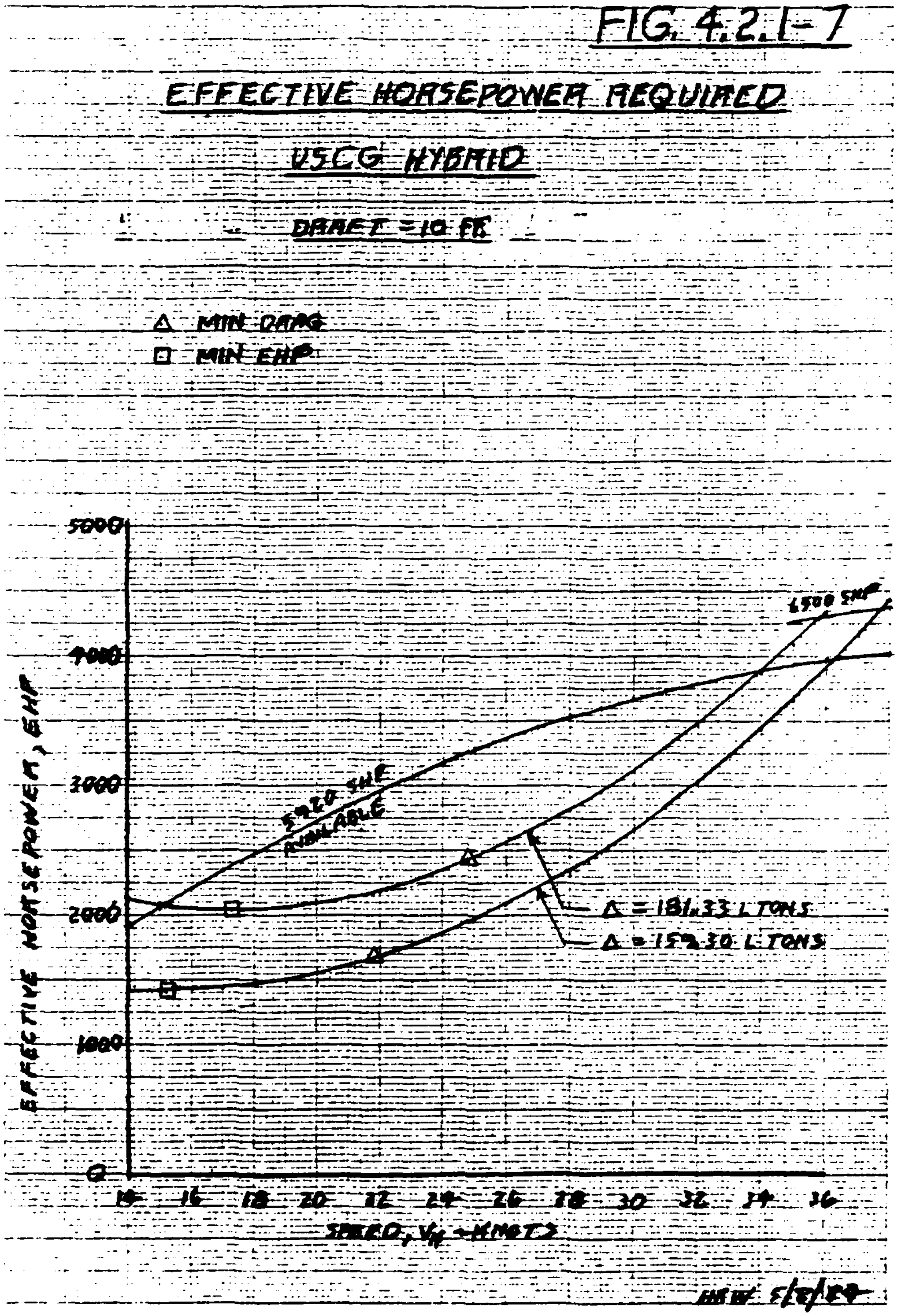


Figure 4.2.1-7. EFFECTIVE HORSEPOWER REQUIRED USCG HYBRID

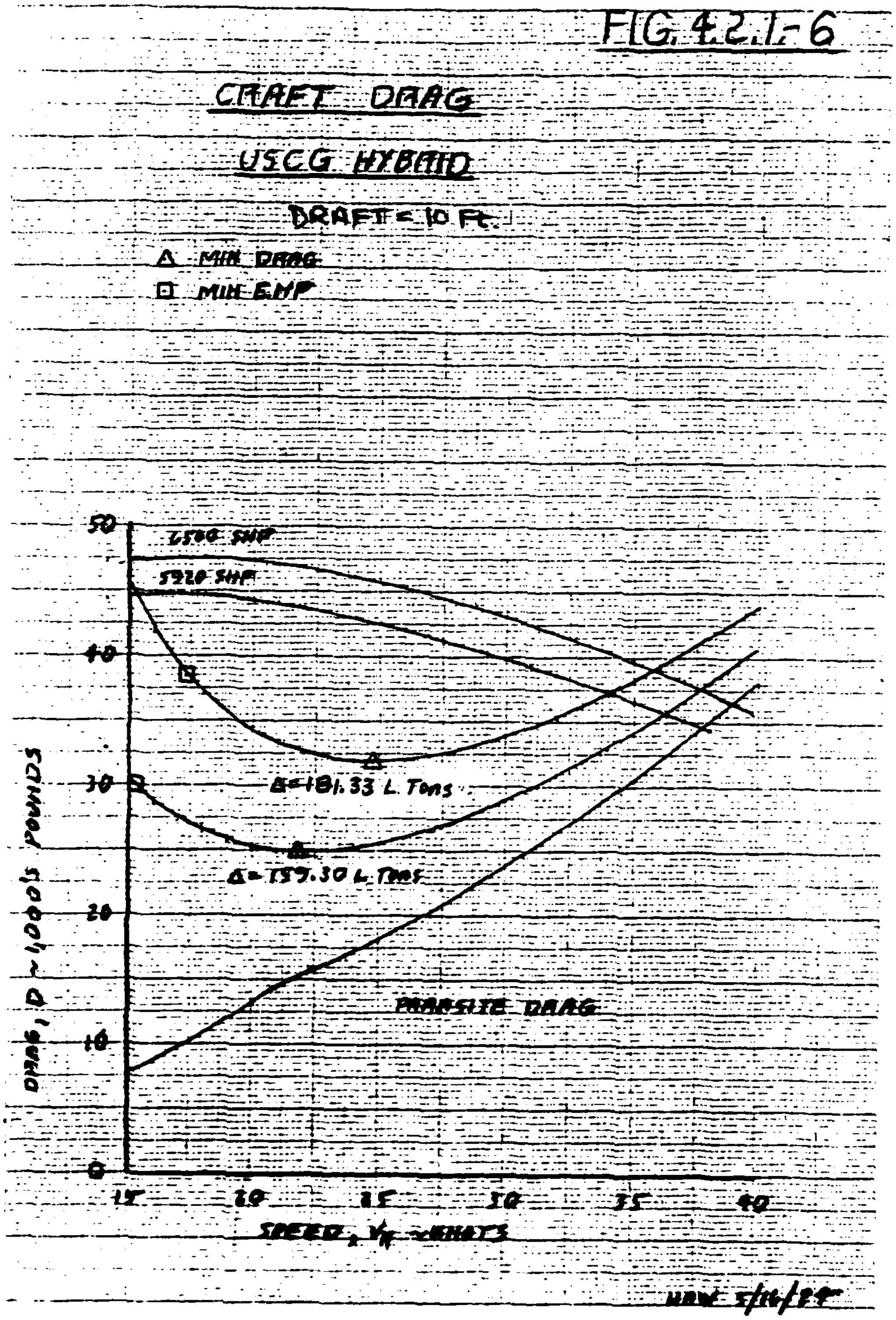


Figure 4.2.1-6. CRAFT DRAG USCG HYBRID

FIG 4.2.1-5

CRAFT DRAG POLAR

USCG HYBRID

DRAFT = 10 ft. Δ = 159.30 L Tons

$$C_D = .026071 + .033253\,C_L + .12055\,C_L^2$$

	C_L	VALUE	V_K		
$(L/D)_{max}$	.46504	6.8787	21.813	MIN. DRAG	△
$(C_L^{1/2}/C_D)_{max}$	.95513	5.5627	15.220	MIN. EHP	□

Δ = 181.33 L Tons

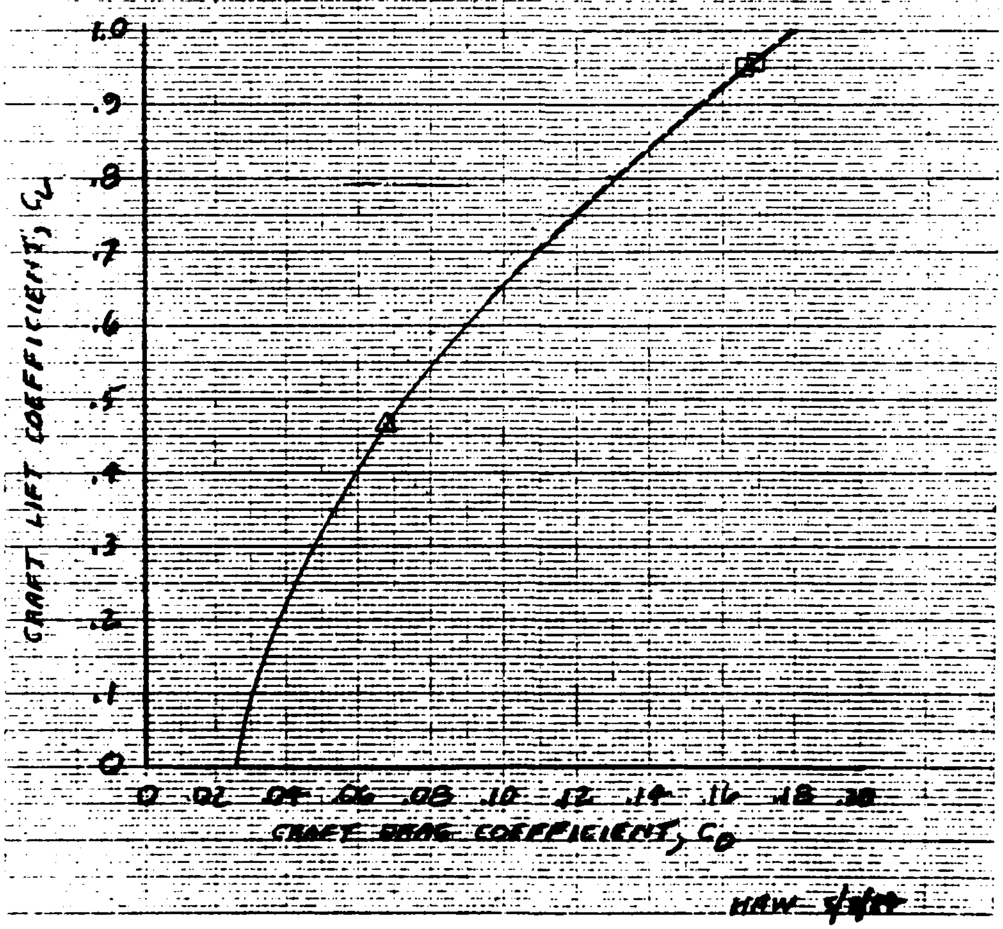


Figure 4.2.1-5. CRAFT DRAG POLAR USCG HYBRID

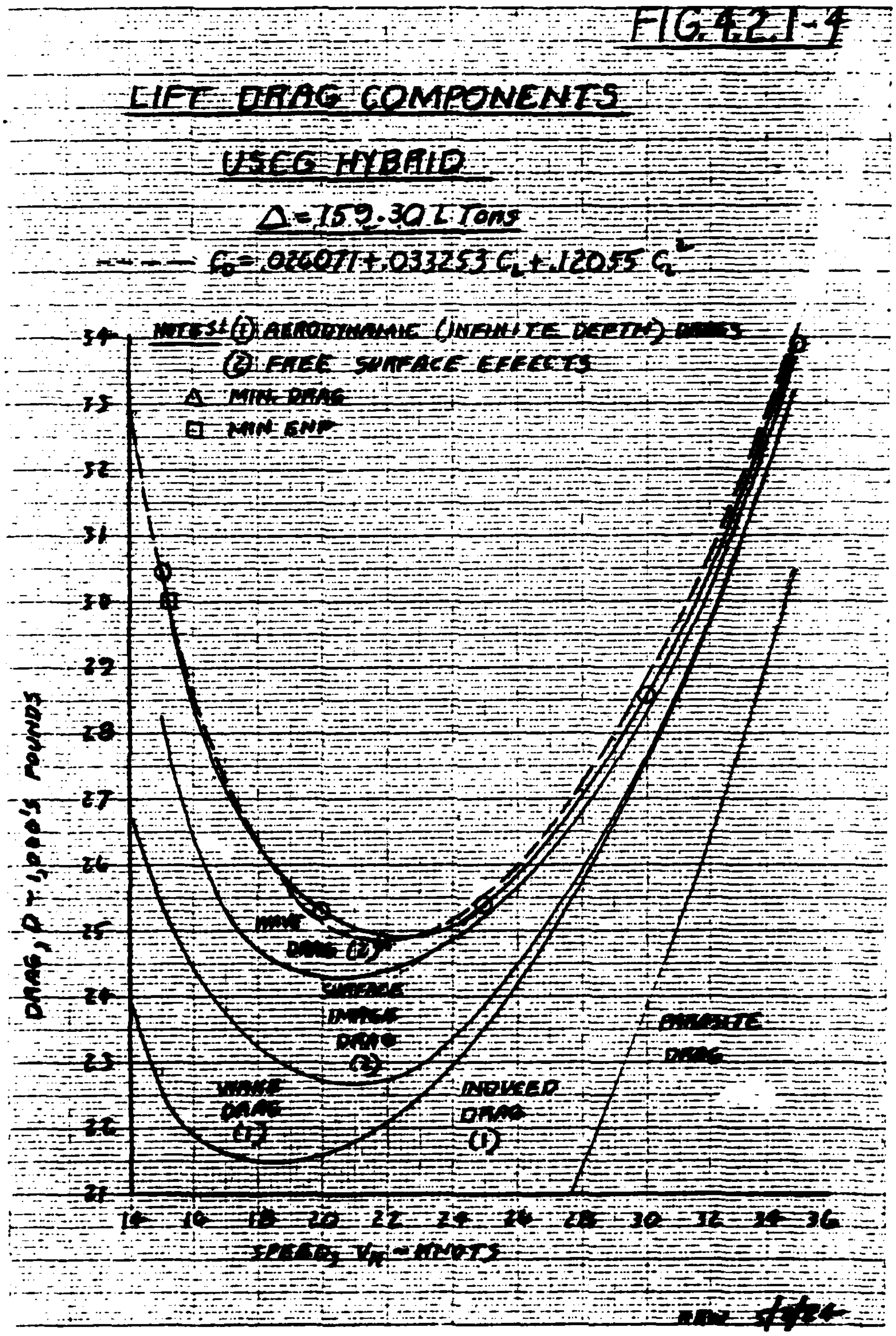


Figure 4.2.1-4. LIFT DRAG COMPONENTS USCG HYBRID

From Equations 4.2.1-3 through 4.2.1-7 the total lift drag coefficient is:

$$C_{D_i} = .088647\ C_L^2 \qquad 4.2.1\text{-}7$$

$$C_{D_{WAKE}} = .00085144 - .009428\ C_L + .026099\ C_L^2$$

$$C_{D_{SURF}} = .016624\ C_L^2$$

$$C_{D_{WAKE}} = .00024949 - .0036705\ C_L + .016611\ C_L^2$$

$$C_{D_L} = .001109 - .013098\ C_L + .14798\ C_L^2$$

and with Equation 4.2.1-2 the total drag coefficient becomes:

$$C_{D_P} = .02497 + .046352\ C_L - .027428\ C_L^2 \qquad 4.2.1\text{-}8$$

$$C_{D_L} = .0011009 - .013098\ C_L + .14798\ C_L^2$$

$$C_D = .026071 + .033253\ C_L + .14798\ C_L^2$$

The calculated lift drags are compared with the total lift drag polar of Equation 4.2.1-7 on Figure 4.2.1-4. The total drag polar of Equation 4.2.1-8 is shown on Figure 4.2.1-5 and the corresponding drag curve for two displacements is shown on Figure 4.2.1-6. The drag curves of Figure 4.2.1-6 are presented as effective power required curves on Figure 4.2.1-7.

It should be noted that the drag calculations throughout this report were for a draft of 10 ft, i.e. for a fully wetted strut. Thus these performance results are conservative for the flight waterline.

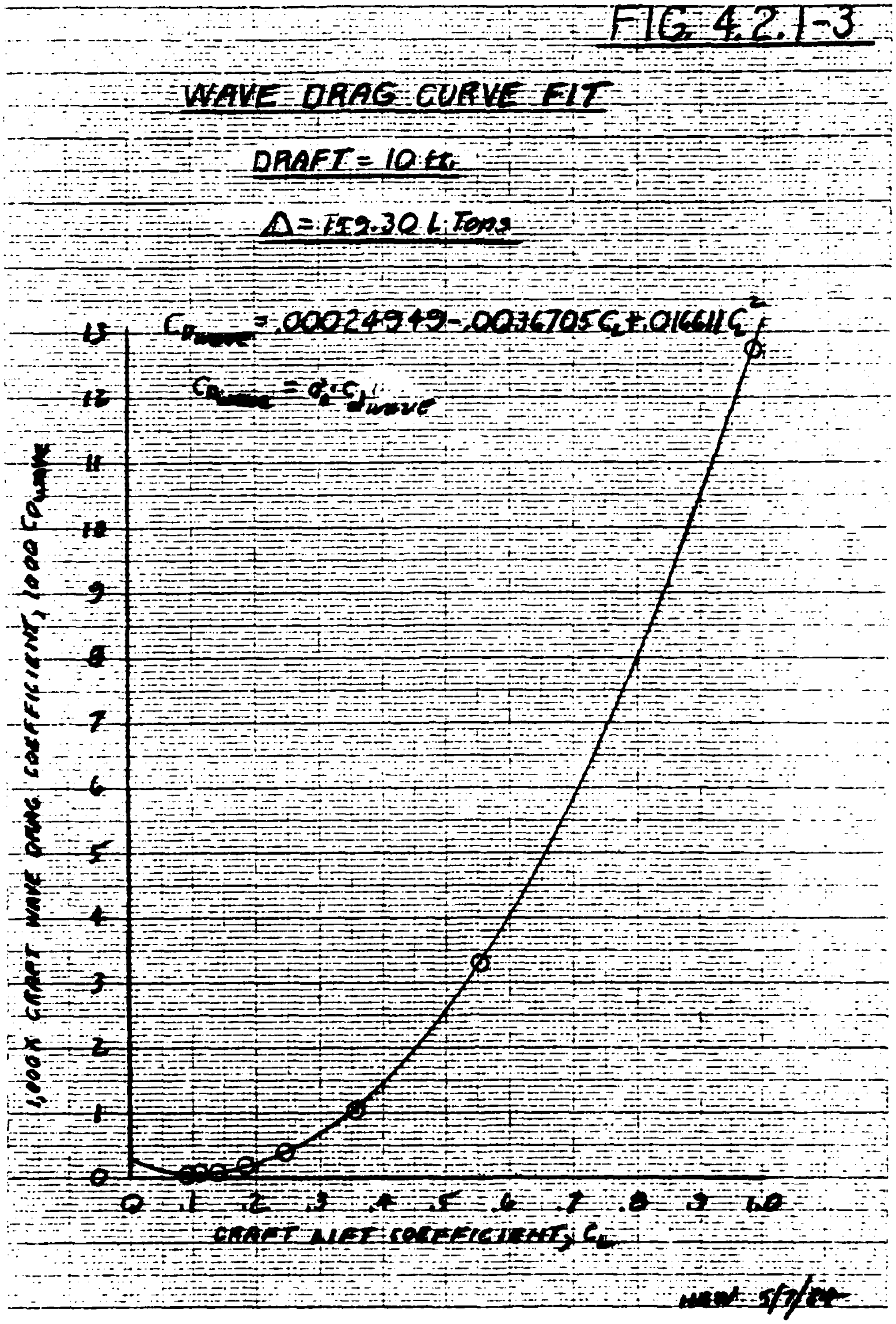


Figure 4.2.1-3. WAVE DRAG CURVE FIT

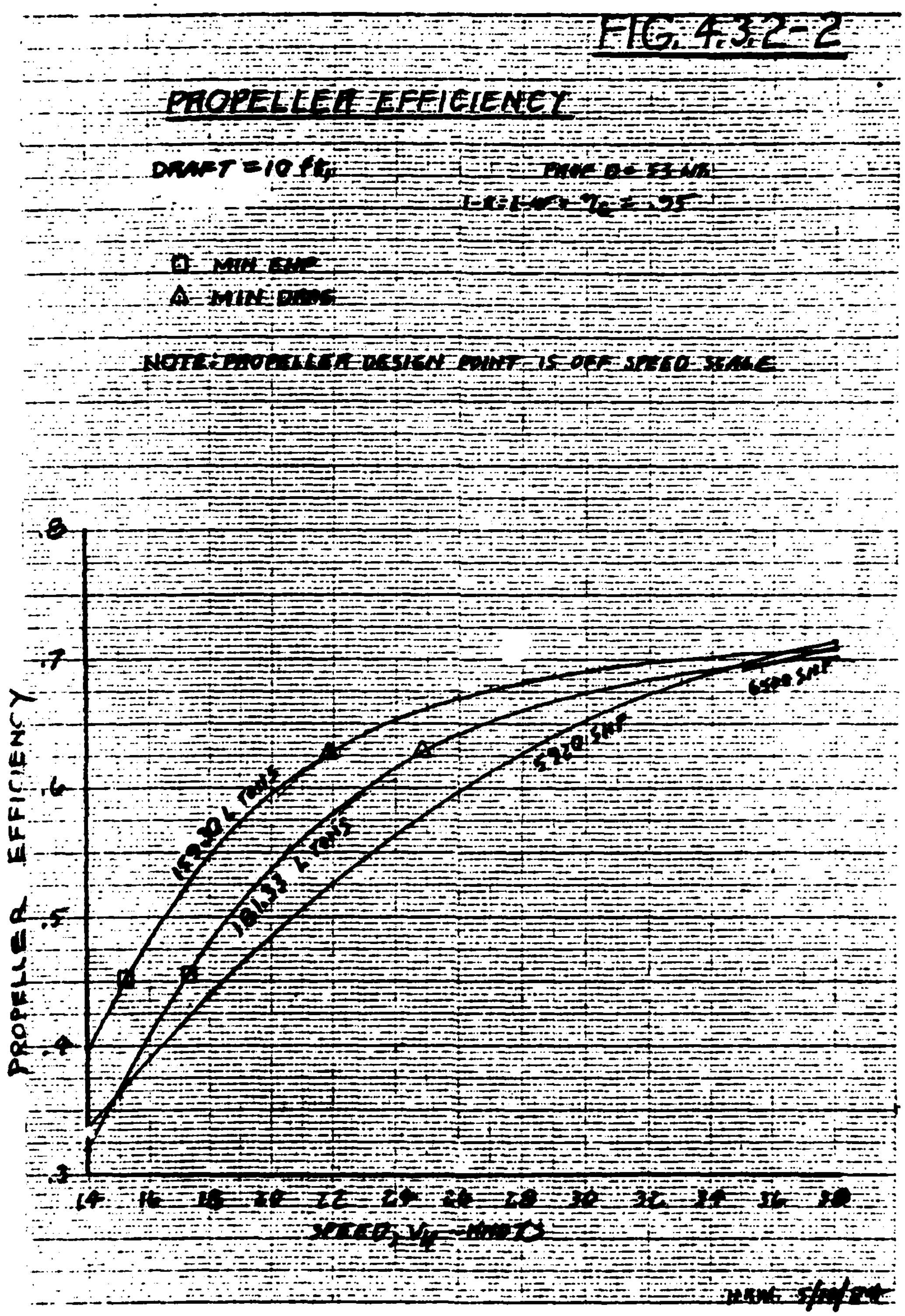


Figure 4.3.2-2. PROPELLER EFFICIENCY

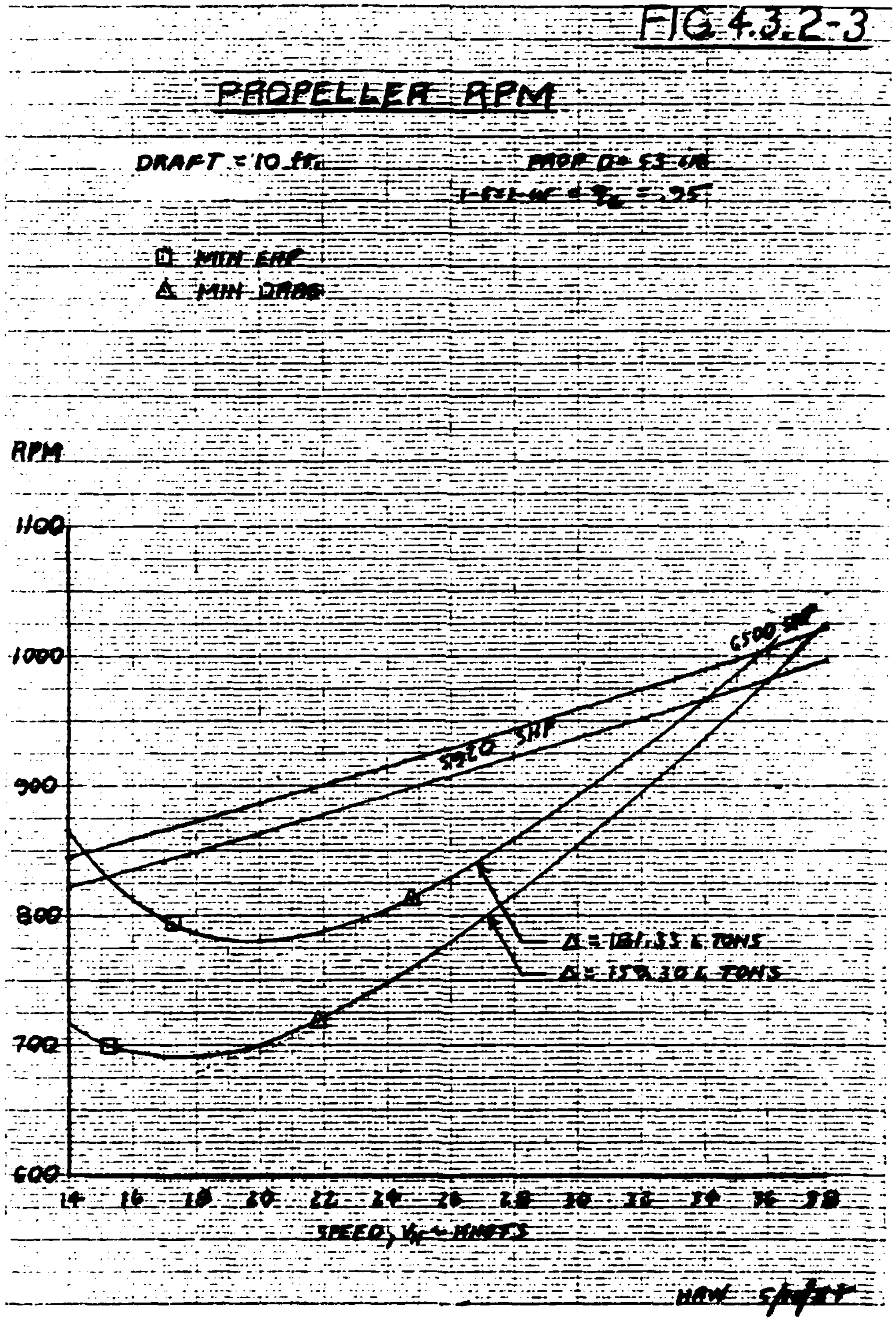


Figure 4.3.2-3. PROPELLER RPM

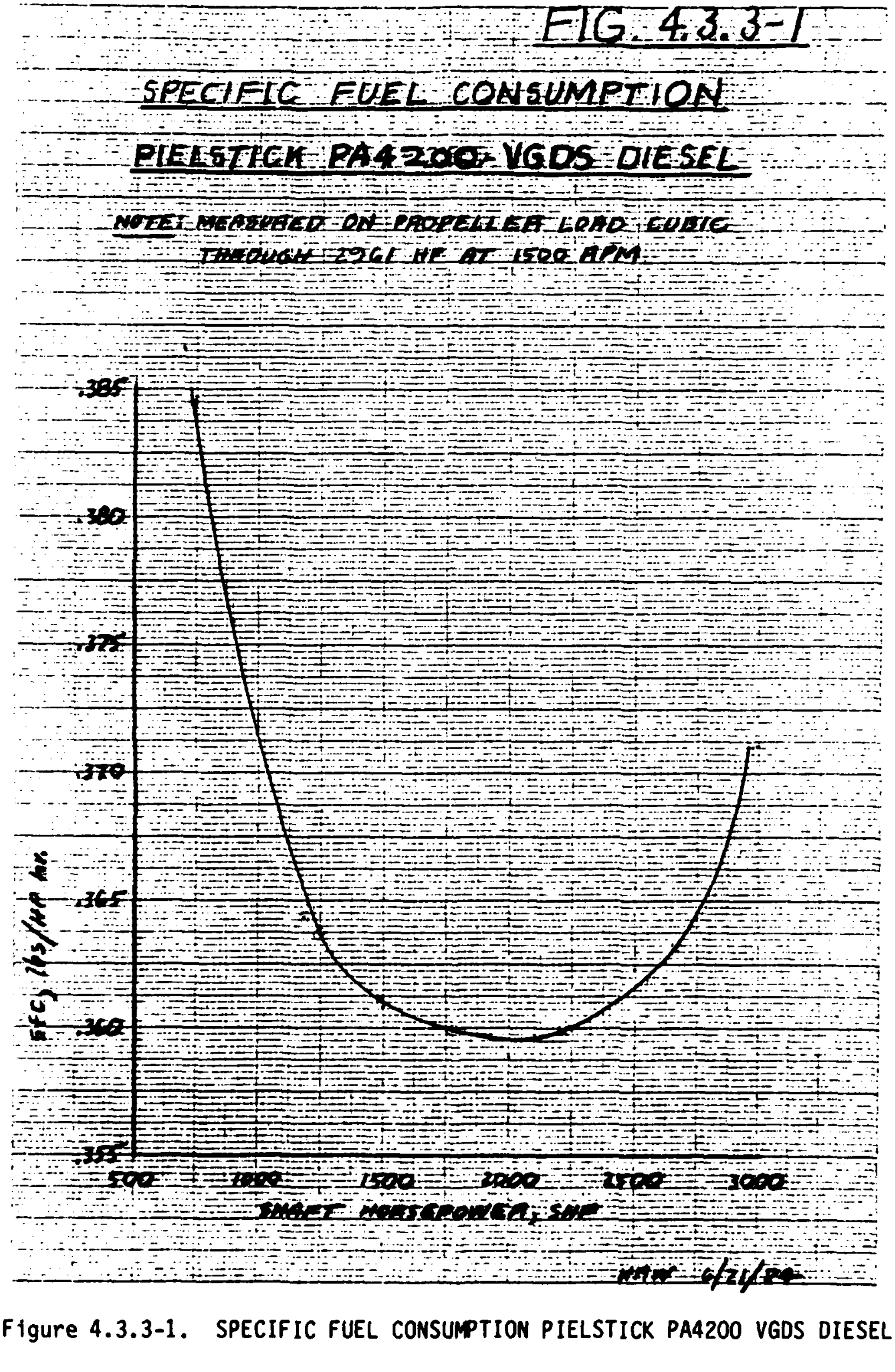


Figure 4.3.3-1. SPECIFIC FUEL CONSUMPTION PIELSTICK PA4200 VGDS DIESEL

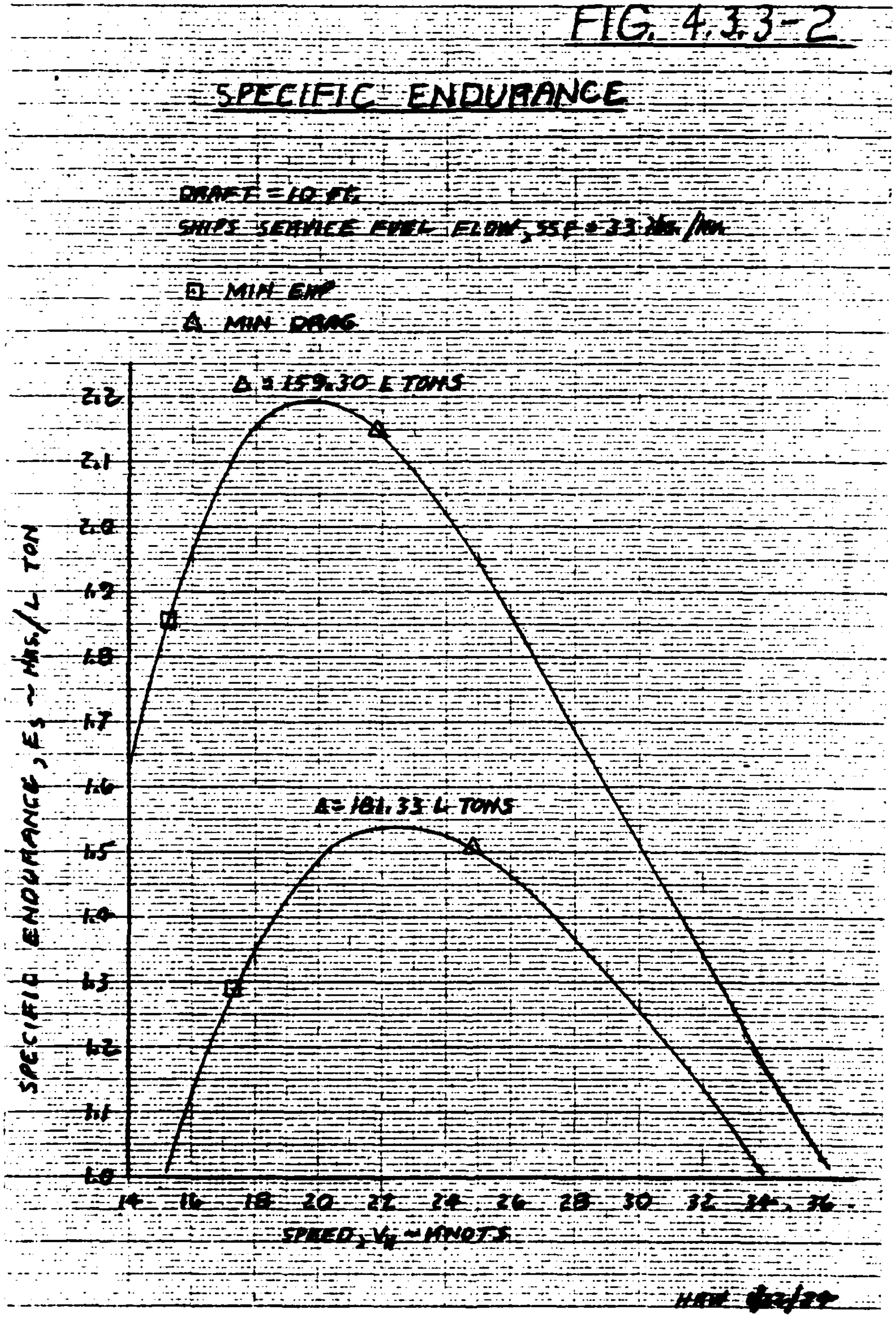


Figure 4.3.3-2. SPECIFIC ENDURANCE

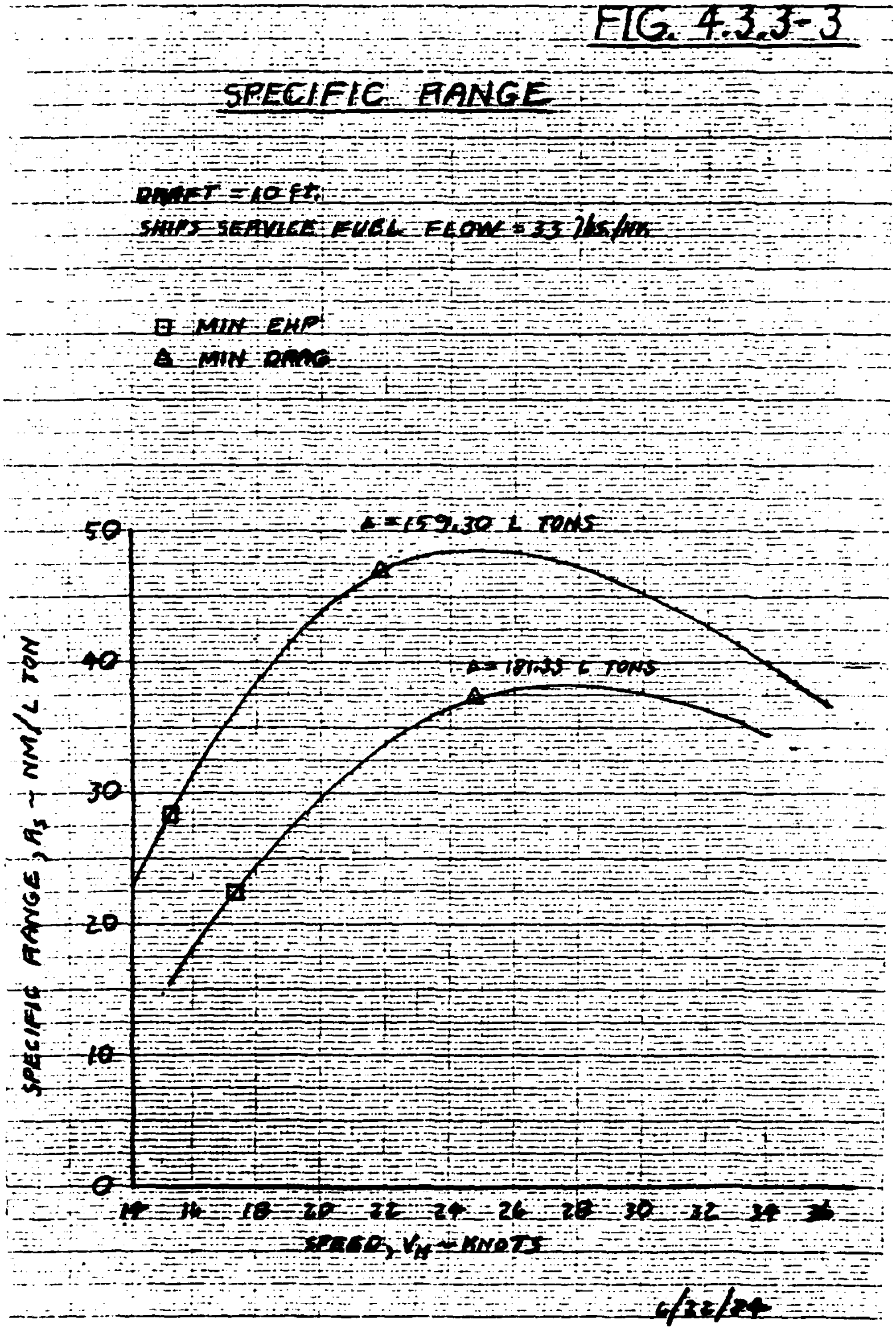


Figure 4.3.3-3. SPECIFIC RANGE

The fixed displacement range and endurance are summarized on Figures 4.3.3-4 and -5 and in Table 4.3.3 for 34.3 tons of fuel.

The 159.3 ton displacement was the mid-fuel-weight at an early point in this study but now represents the displacement with 64% of the fuel burned off. The range and endurance for this case are retained here for reference. The fuel/ballast management characteristics for this craft preclude adequate accountability for Breguet effect in the time available for this study. The ranges and endurances of Table 4.3.3 are for the most conservative fuel/ballast management; Figure 4.3.3-2 and -3 indicate the benefits to be gained by not ballasting for burned fuel.

4.3.4 Hullborne Performance

For the propeller characteristics of Section 4.3.1 the hullborne drag curve of Figure 4.2.3-1 becomes the power required curve of Figure 4.3.4-1. In this power range Equation 4.3.3-1 becomes:

$$E_s = 2240/(SFC\ SHP + SSF) \qquad \text{hrs/L.ton} \qquad 4.3.4\text{-}1$$

where: $SFC = .44485 - .05318 \dfrac{SHP}{1000} + .0082673 \left(\dfrac{SHP}{1000}\right)^2$

$1480 \leq SHP \leq 3554$

SHP = Total SHP, 2 engines

SSF = ship's service fuel flow = 33 lbs/hr

The variation of specific endurance and range with speed is shown on Figure 4.3.4-2. In the hullborne mode for example, range is 2600 n. miles and endurance is 208 hours at 12.5 knots using 34.3 L.tons of fuel.

4.3.5 Mixed Mode Performance

A mixed mode (hullborne and foilborne) 5-day operation was assumed with 24 hours foilborne and 96 hours hullborne. Specific ranges were taken at the half-fuel load condition and several examples computed to consume 34.3 L.tons of fuel available. This takes into account a 10% reserve from the

38.1 L.tons of fuel useable. For example, the M174 design provides a total mixed-mode range of 1968 n. miles operating at 30 knots for 24 hours and 13 knots for 96 hours.

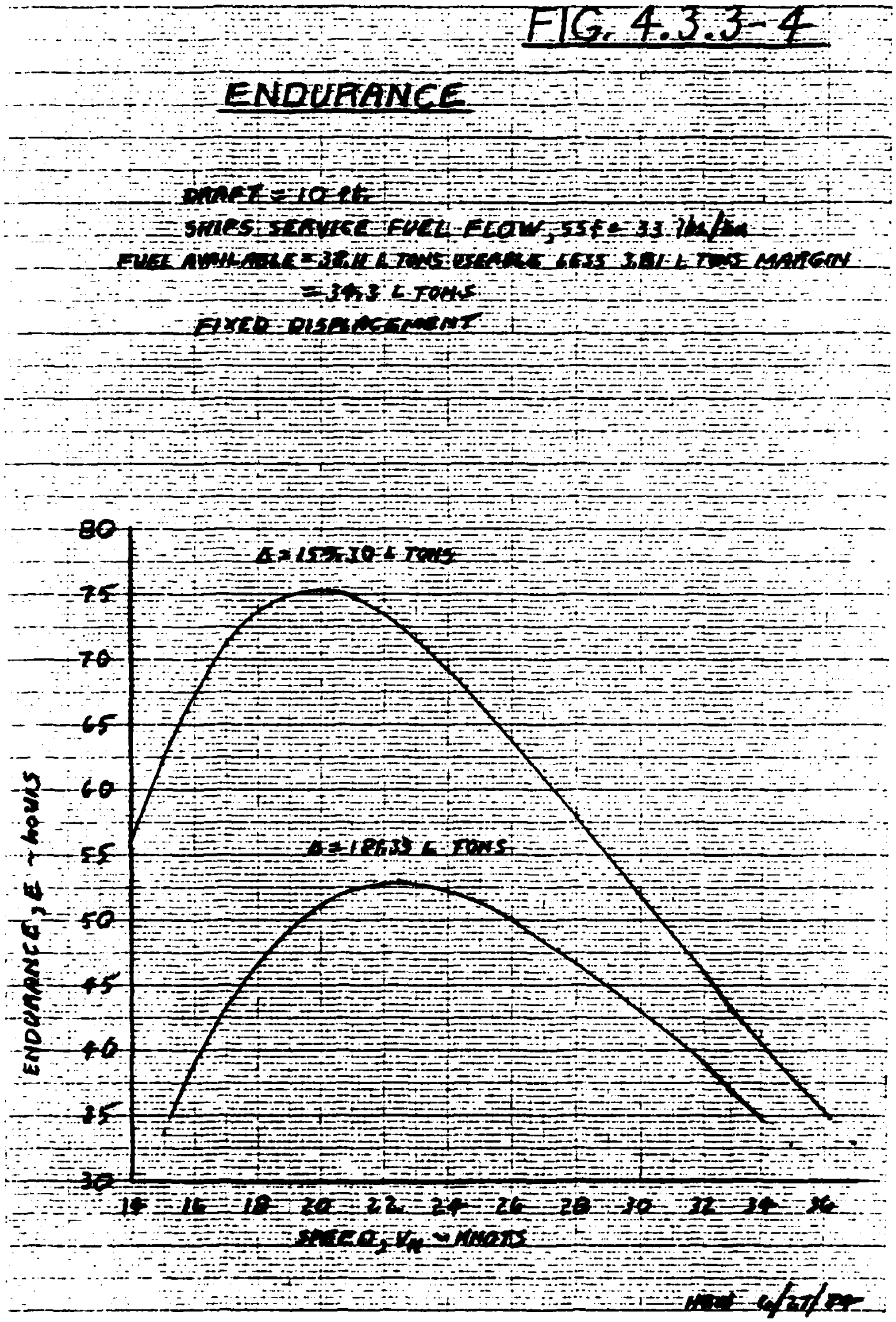


Figure 4.3.3-4. ENDURANCE

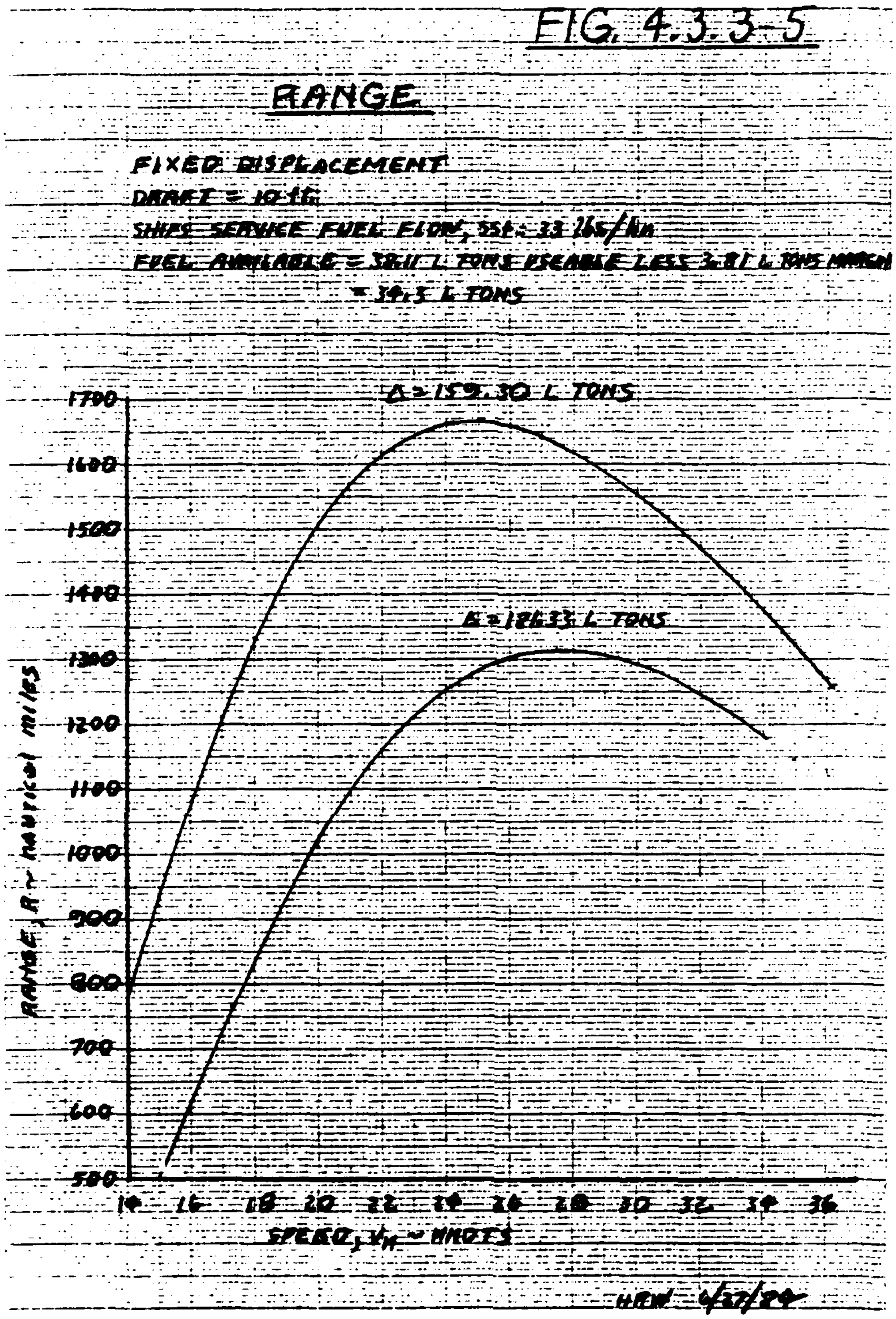


Figure 4.3.3-5. RANGE

Table 4.3.3

FIXED DISPLACEMENT RANGE AND ENDURANCE

Speed Knots	Specific Endurance E_S Hrs/L.ton	Endurance E Hrs	Specific Range R_S NM/L.ton	Range R NM
		Δ = 181.33 L.TONS		
22.5 knots Maximum Endurance	1.54	52.8	34.65	1188
27.5 Knots Maximum Range	1.393	47.8	38.3	1314
34.1 Knots Maximum Speed	1.007	34.5	34.35	1178
		Δ = 159.30 L.TONS		
20 Knots Maximum Endurance	2.196	75.3	43.92	1506
25 Knots Maximum Range	1.942	66.6	48.55	1665
36.2 Knots Maximum Speed	1.015	34.8	36.74	1260

NOTES: Range and endurance are for 34.3 tons fuel. Fuel replaced with ballast as burned.

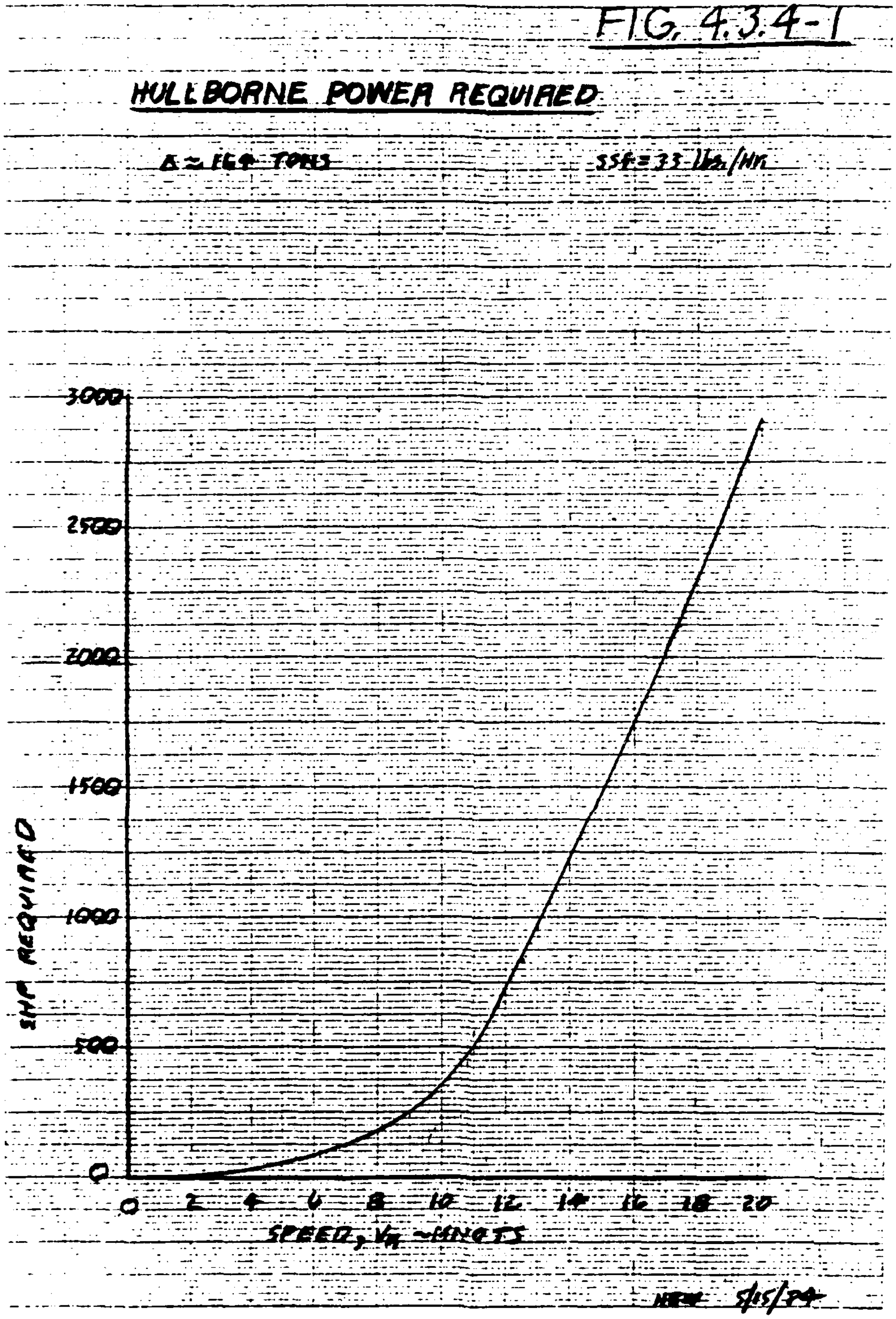


Figure 4.3.4-1. HULLBORNE POWER REQUIRED

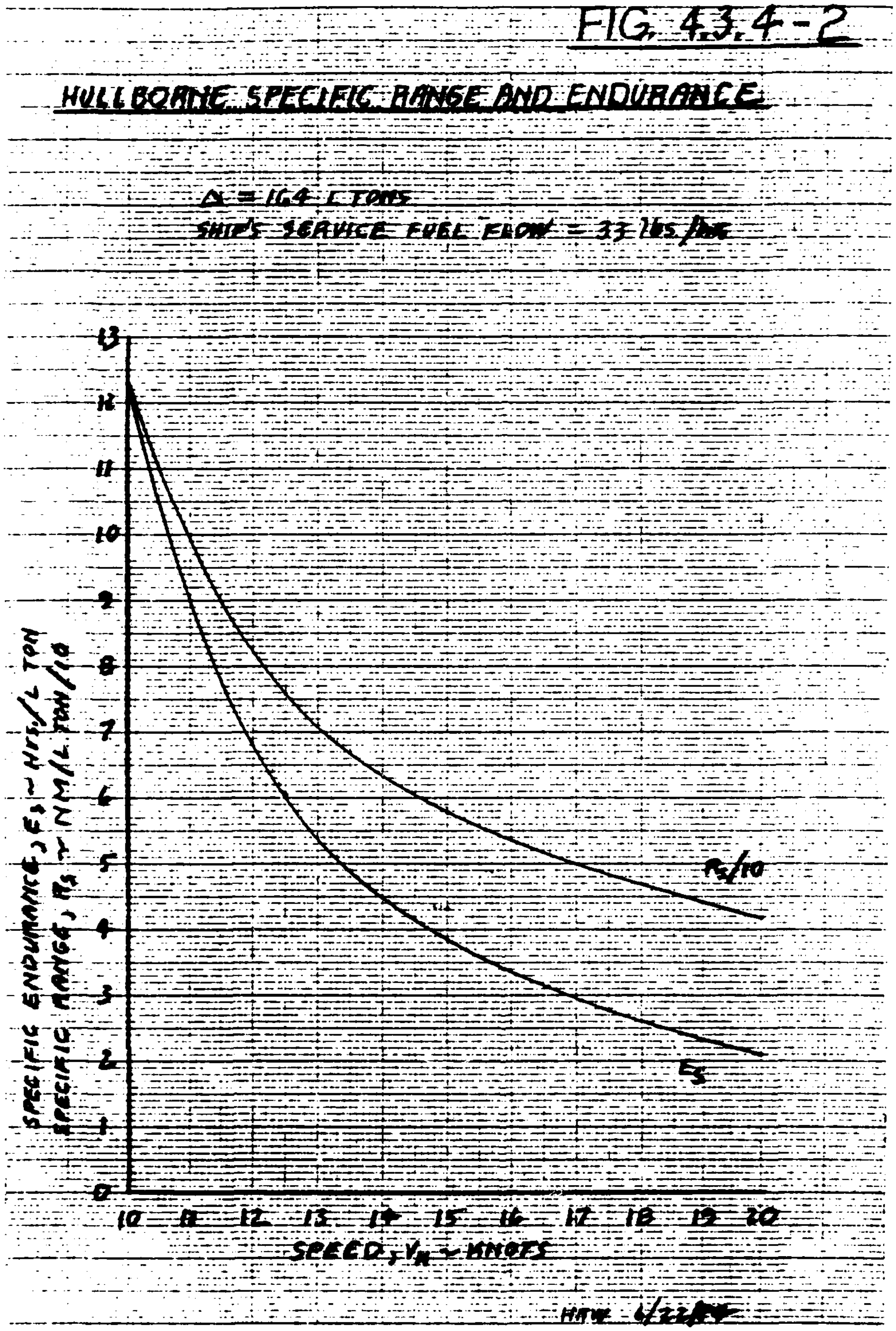


Figure 4.3.4-2. HULLBORNE SPECIFIC RANGE AND ENDURANCE

4.4 Maneuverability

4.4.1 Turning Performance

Foilborne turning performance has not been rigorously analyzed for the particular hybrid configuration described in this report because it is beyond the scope and funding of this study. However, there are certain observations that can be made that relate to this characteristics. Hydrofoils are well known for their high turn-rate capability, since they bank to turn and the control system is usually designed to produce a coordinated turn. Rates of 6^{o} to 8^{o} per sec at 40 knots or more are normal for hydrofoils with fully submerged foil systems. The addition of a large buoyancy/fuel tank to a fully submerged foil system is predicted, from reference 8 computer simulation of the Extended Performance Hydrofoil (EPH) PCH-1 Feasibility Demonstrator, to be degraded by only about 25%. However, it should be noted that during model tests of the EPH configuration (see reference 9) that full-scale foilborne turn rates of up to 8^{o} per second were accomplished. This implies that no degradation in turn rate of EPH may be experienced. The use of a long central strut in place of the four separate relatively short chord struts of the EPH model introduces an element of the unknown into the picture, and would be expected to add directional stability (reduce achievable turn rates). The use of a large rudder in the current Hybrid design tends to follow the lessons learned from the EPH model and provides a reasonable assurance that turn-rates of 4 to 6 degrees per second at 35 knots may be achieved.

4.4.2 Hullborne Maneuverability

The issue of foilborne maneuvering is centered on the capability of the hybrid form discussed in this report to safely maneuver in a harbor in the presence of other vessels or objects, and dock under reasonable conditions of wind and currents. The combination of large rudder and fully rotatable (360^{o}) outdrive is expected to assure safe harbor operations, docking and undocking without any particular problems particularly if a bow thruster is installed. The latter may be necessary on the M174 design in view of the

increased lateral plane area due to the strut and tank, and effects of current on their additional area. At low hullborne speeds the M174 will not be as maneuverable as the current WPB.

The main foil overhang of about 5 ft beyond the main hull can be accommodated by the use of camels and/or a foil guard added to the hull over the main foil location. A foil guard is currently used on HIGHPOINT (PCH-1) R&D hydrofoil and has been satisfactory in over 20 years of operations. The PHM hydrofoils utilize a floating platform between the ship and pier to accommodate an aft foil overhang of about 9 ft.

4.5 Motions

As in the case of Maneuverability, funding for this feasibility study did not permit a rigorous treatment of motions prediction of the Hybrid Concept described in this report. An understanding of motions to be expected of this hybrid design may be derived from a long history of hydrofoil experience and model tests of EPH as documented in Reference 9. For example, Figure 4.5.1 shows a comparison of HIGHPOINT (PCH-1) trials and simulation data compared with EPH model tests. The PCH-1 vertical acceleration data are for the pilot house location, whereas model data is for bow and center of gravity locations. One can see that EPH "pilot house" data would fall above, but close to, PCH-1 data indicating only a small degradation in vertical motions due to an addition of a buoyancy/fuel tank.

Additional relative vertical acceleration measures are shown in Figure 4.5.2. Here, data for the c.g. location are plotted for WPB, Bell-Halter SES, RHS-160, JETFOIL, and EPH model testss. A band indicating anticipated motions of the USCG Hybrid Concept described in this report is also shown as a probable estimate.

Figure 4.5.3 depicts pictorially the relative position of an existing WPB and the hybrid design in a 10-foot high wave system (comparable to significant wave height of mid Sea State 5). It can readily be appreciated from this representation that although the upper hull of the hybrid form will be

Table 5-2

STANDARD CELL CONSTRUCTION

Code No.:	XUS-784 UNIROYAL
Type:	Tear Resistant Non-Sealing Bladder
Use:	Gasoline, Jet Fuel, Kerosene
Issued to:	Mishawaka R&D
Date:	August 10, 1979

Material (from inside out)	Guage Inches	Weight Lbs/Sq Ft
*Liner (1 ply 5200)	.009	.040
Nylon Barrier & Cement Coats	.003	.030
**Outer Shell (1 ply D-763 or equivalent 7/2/79)	.030	.151
	.042	.221

Table 5-1

USCG HYBRID CONCEPT - FOIL LOADINGS

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - FOIL LOADINGS			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
EEH			5/16/84	1

MAIN FOIL AREA = 210.00 ft² = 77.3%

AFT FOIL AREA = 61.75 = 22.7%

TOTAL FOIL AREA = 271.75 ft² = 100%

		LCG	MOM
FULL BALLAST COND.	181.33	45.66	8279.78
LESS TANK/STRUT BUOY	− 79.54	44.92	− 3572.90
	101.79	46.24	4706.88
ASSUME:			
FWD STRUT	−3.05	38.25	− 116.66
AFT STRUT	−0.51	79.75	− 40.67
DYNAMIC LIFT	98.23	46.32	4549.55

LOAD DISTRIBUTION

$98.23 \times \frac{33.43}{41.50}$ = 79.13 LT ON FWD FOIL = 81%

TRY FULL FUEL DISTRIBUTION

FULL FUEL DISPL -	181.06	47.61	8620.65
LESS TANK/STRUT BUOY	− 79.54	44.92	− 3572.90
	101.52	49.72	5047.75
FWD STRUT	− 3.05	38.25	− 116.66
AFT STRUT	− 0.51	79.75	− 40.67
DYNAMIC LIFT	97.96	49.92	4890.42

LOAD DISTRIBUTION

$97.96 \times \frac{29.83}{41.50}$ = 70.41 LT ON FWD FOIL 72%

conditions at the aforementioned distribution. A compromise location, as shown on Figure 3-1, was calculated as shown on Table 5-1 which overloads the forward foil by 3.2 tons in the full ballast condition and the aft foil by 5.3 tons in the full fuel condition. As an overloaded aft foil will degrade performance, filling the aft tank to capacity should not be contemplated unless absolutely necessary for a prospective mission.

Foil construction was not analyzed except as necessary for the weight estimation of Section 8. It is assumed that the forward foil would, for economical reasons, be constructed in the conventional beam and rib method of streamlined rudders. While, for a normal hydrofoil, weight would be of the utmost importance, the configuration of the Design M174 requires that weight be concentrated in the tank area and that therefore light weight composite material would be of little overall value.

There are, however, a number of viable alternatives to conventional construction which could be considered. Chief among these would be a steel box structure embedded in a molded urethane-based material shell.

The aft foil size appears to be within the limit for forged aluminum, similar to the construction methods used on previous Grumman hydrofoils and would lend itself to full incidence control as previously noted in Section 4.

5.4 Fuel Cells

The tank fuel cell bladder construction has been discussed in general with the Uniroyal Corporation, a principal fabricator of fuel cells for aircraft and missiles.

Basically, the cells would be constructed of material as noted on Table 5-2 and molded around a perforated fill/suction tube on the vertical axis. A flange, top and bottom, would attach the assembly to the tank structure. The lower flange would be secured to the access manhole cover to permit easy installation, and the upper flange would provide the watertight seal to the strut interior. The fabric cell would include, an as yet

In the fuel cells, the manhole covers would also serve as the lower support for the bladder fill and suction tube as shown on Figure 5-1.

5.2 Strut

The strut is a welded steel assembly with parabolic leading and trailing edges and a parallel middle body. Stiffening and support is provided by six vertical diaphragms and intermediate angle stiffeners.

While no personnel access is provided into the strut, hand holes must be installed in way of each fuel cell in order to connect the watertight seal at the top of the bladder fill/suction tube to the strut piping.

To provide a structural attachment for the strut to the hull, the strut is carried up as a trunk into the hull between the engine room bulkheads. The top of the trunk forms a watertight closure and also the foundation for the ships service generators.

The derivation of the strut scantlings is also given in Appendix B.

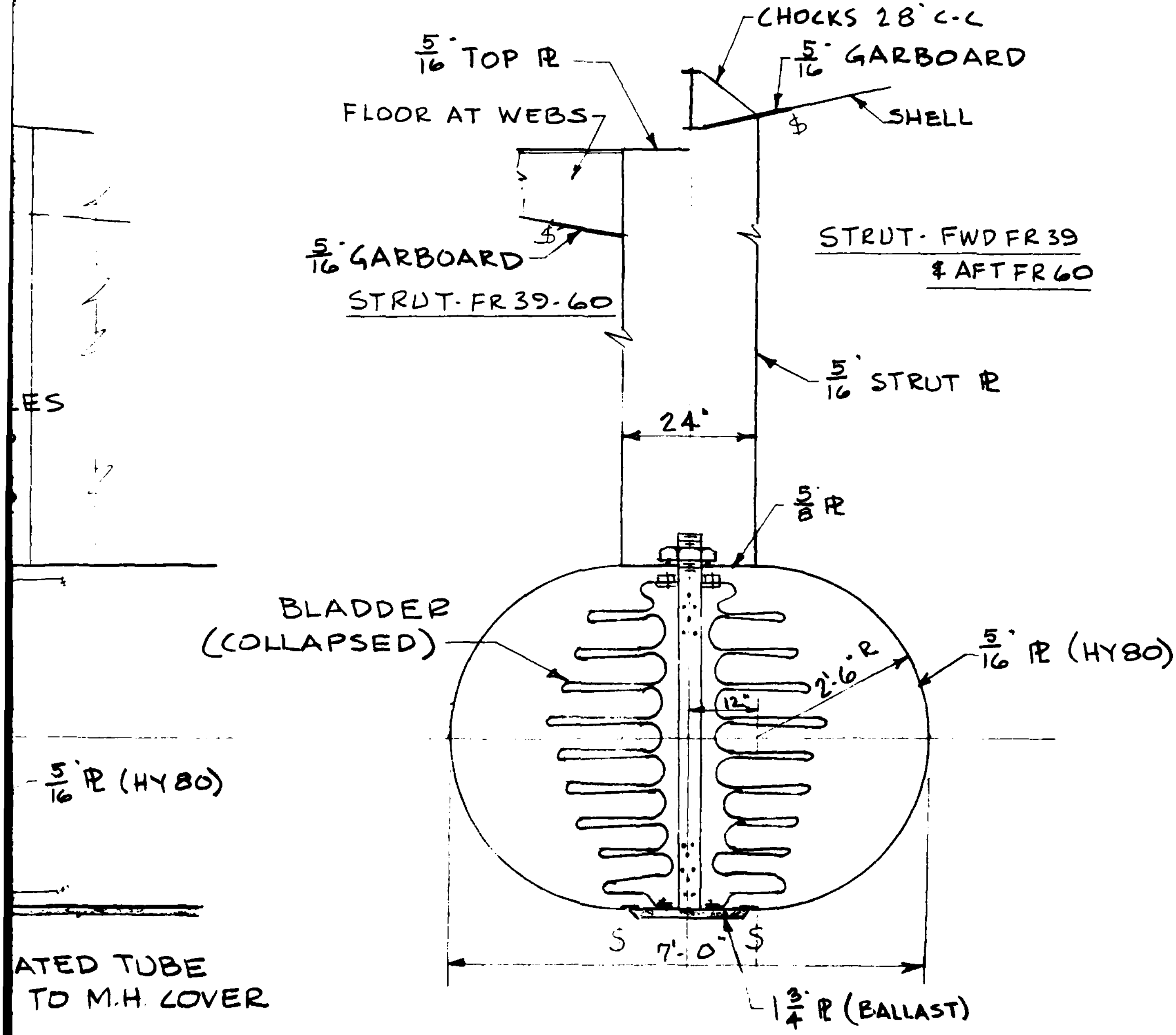
The trailing edge of the strut provides support for a single streamlined unbalanced rudder which serves for both hullborne and foilborne operation.

5.3 Foils

The hydrodynamic characteristics of the foil system have been adequately discussed in Section 4. Based upon the pre-selected foil areas and uniform loading, the foil load distribution is divided between 77.3% on the forward foil and 22.7% on the aft foil.

Due to the large fuel tank surrounding the shaft tube aft, which is not adaptable to a bladder installation, there is an excursion of approximately two feet in the LCG between the full fuel and full ballast condition. It is therefore not possible to locate the foils to satisfy both loading

2



T TANK AND FUEL BLADDER

USCG HYBRID CONCEPT

TYP BALLAST TANK & FUEL BLADDER

SCALE: 1/2" = 1'-0"

FIGURE 5-1

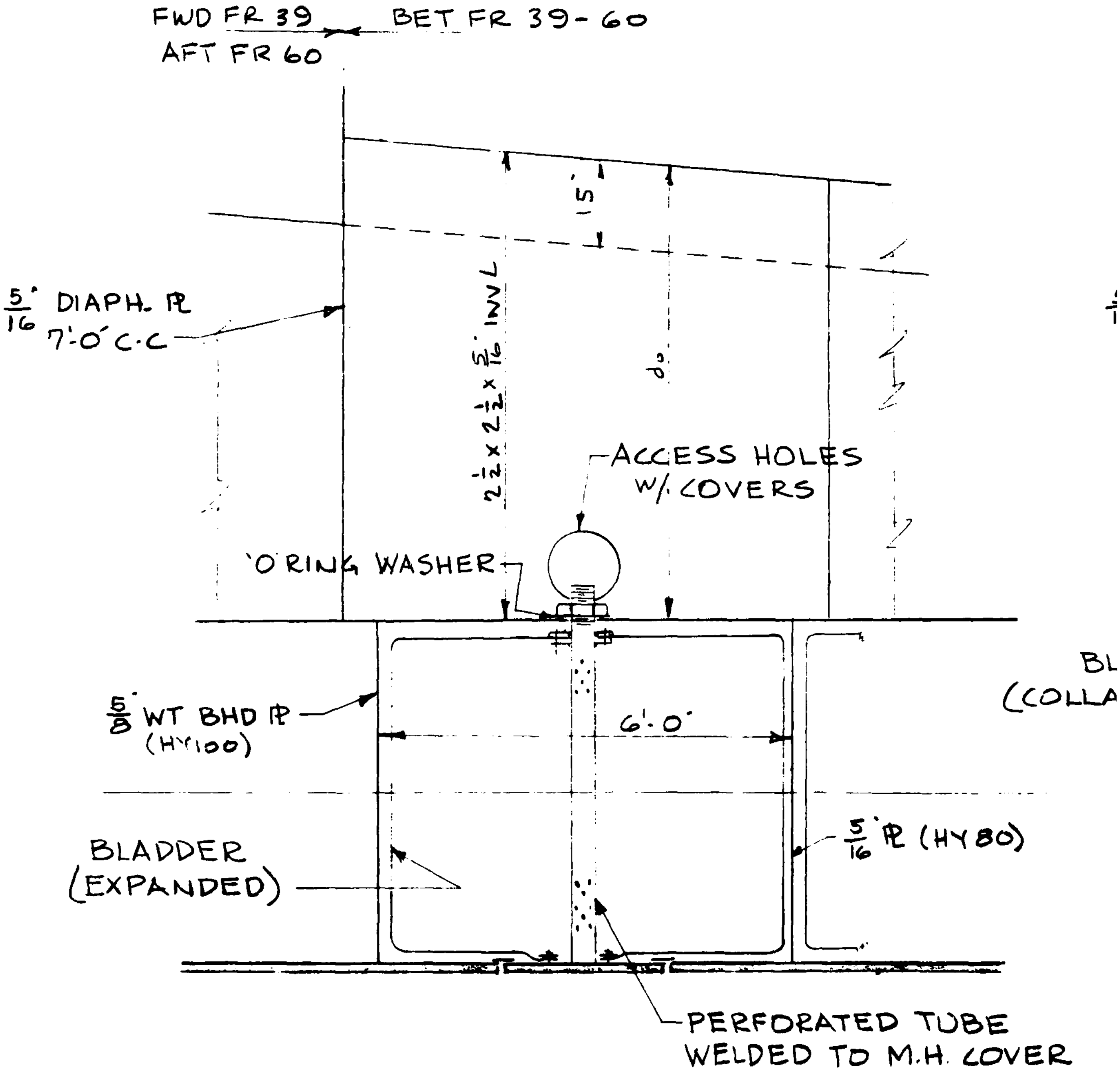


Figure 5-1. USCG HYBRID CONCEPT BALLAST TANK AND FUEL BLADDER

SECTION 5

BUOYANCY/FUEL TANK, STRUT AND FOILS

5.0 General

The buoyancy/fuel tank is basically a flat circular section with 30" radii separated by a 24" flat top and bottom. The nose is an ellipsoid and the tail section a paraboloid in elevation. It is supported by a single strut of constant cross-section. The hydrofoils are of the airplane configuration as discussed in Section 4, and are attached to the tank at the locations shown on Figure 3-1.

5.1 Buoyancy/Fuel Tank

The buoyancy/fuel tank is a welded steel assembly with a glass-reinforced plastic nose cone. The scantlings were calculated by classic methods with no recourse to more rigorous analysis methods due to program constraints. To maintain a smooth interior, both shell and bulkheads are considered as unsupported structure with no internal stiffening. Seven watertight bulkheads are positioned to subdivide the tank into cells twelve feet long for the fuel bladders and also to isolate the strut mounting section. The twelve foot long cells are then divided in two in order to maintain a maximum bladder length of six feet. The general arrangement of the tank construction and bladder is shown on Figure 5-1. The derivation of the scantlings is presented in Appendix B. Unfortunately in order to provide a reasonable margin of intact stability it became necessary to add ballast structure to the tank. Although it is realized that construction will be more difficult because of it, the addition of an extra heavy keel plate is the most advantageous method for lowering the center of gravity and therefore is shown on Figure 5-1.

It is proposed that access to the various cells within the tank will be through 30" x 24" manholes in the flat bottom keel plate. As previously noted, fabrication will be more involved due to the heavy keel strake, but it is felt that it is preferable to installing the manholes in the curved surfaces.

Table 4.6

USCG HYBRID CONCEPT COMPARISON

ITEM	HYBRID CONCEPT	WPB CLASS	SEUS WPB
Displacement; L.tons	181	105	161.0
Draft; ft	14	6.3	7.3
LOA; ft	95	95	110
LBP; ft	90	90	105
MAX. BEAM; ft	30 Across Foils	20 At Deck	21 At Deck
MAX. Cont. Power; hp	5920	2400	5760
Fuel Load; L.tons	38	9	30.6
Crew	14	14	15
MAX. SPEED, kts (full load)	34	21	29.7
Range; n. miles (calm water)	4180 at 10 kts 2600 at 12.5 kts 1660 at 25 kts	3000 at 9 kts 460 at 21 kts	2640 at 13.1 kts 1058 at 26 kts
Endurance; hrs (calm water)	208 at 12.5 kts 66 at 25 kts	333 at 9 kts 22 at 21 kts	201 at 13.1 kts 40.7 at 26 kts
5-Day Mission (calm water)	24 Hrs at 30 kts 96 Hrs at 13 kts 1968 n. miles	N/A	24 Hrs at 26 kts 96 Hrs at 13.1 kts 1882 n. miles
Motions - Single Amplitude Significant Vertical Acceleration in G's at C.G.	EST. .2 at 30 kts in SS-4	.40 at 18 kts in SS-4	.38 at 26 kts in SS-3 .85 at 26 kts in SS-5

4.6 USCG Hybrid Concept Comparison

For the purposes of comparison, Table 4.6 shows several of the major physical and performance characteristics of the USCG Hybrid Concept (M174 design), the current WPB class patrol boats and the recently acquired South East US (SEUS) WPB patrol boats. The improvements in range, speed and motions predicted for the hybrid concept compared to the planing craft is readily apparent.

Table 4.5

COMPARISON OF EPH RUNS (FULL SCALE VALUES)*

SPEED:	33.5 KTS
WAVE CONDITION:	REGULAR
WAVE HEIGHT:	8.3 FT.
WAVE LENGTH:	150 FT.
HEADING:	180°
MANEUVER:	ZIG-ZAG

RUN NO.	FLYING HEIGHT	TRANSFER FUNCTIONS			RMS VALUES		
		PITCH AMPLITUDE (AMPLITUDE / WAVE SLOPE)	HEAVE ACCELERATION (AMPLITUDE / WAVE AMPLxWe^2) (C.G.)	BOW ACCELERATION (AMPLITUDE / WAVE AMPLxWe^2)	PITCH (RMS) DEGREES	HEAVE ACCEL. AT C.G. (RMS g's)	BOW ACCEL. (RMS G'S)
248	High	.0957	.105	.26	.733	.067	.19
249	Low	.0569	.0323	.116	.645	.041	.13
		.0789	.0433	.156	.645	.041	.13
250	High	.0484	.0422	.122	.670	.065	.19
		.0600	.0603	.18	.574	.065	.19

*From Reference 9.

impacted by wave tops, the motions there from are likely to be similar to the WPB in a much smaller wave system. Further evidence of this trend can be derived from the fact that during certain EPH test model runs, the upper hull ran closer to the water surface than programmed. These were first considered "bad" runs, but subsequent review of video tapes and movies indicated that the motions did not appear visually to be any greater than on "good" runs when the keel rode higher above the mean water surface. This visual observation is further verified by the data in Table 4.5 and augmented by a video tape of EPH model test runs 248, 249, 250, and others.

It is therefore projected that motions, both hullborne and foilborne, of the hybrid design will be greatly improved over the WPB and allow high-speed operations between 30 and 35 knots in rough water up thru mid Sea State 5. Ride quality and associated crew performance will likewise be significantly enhanced.

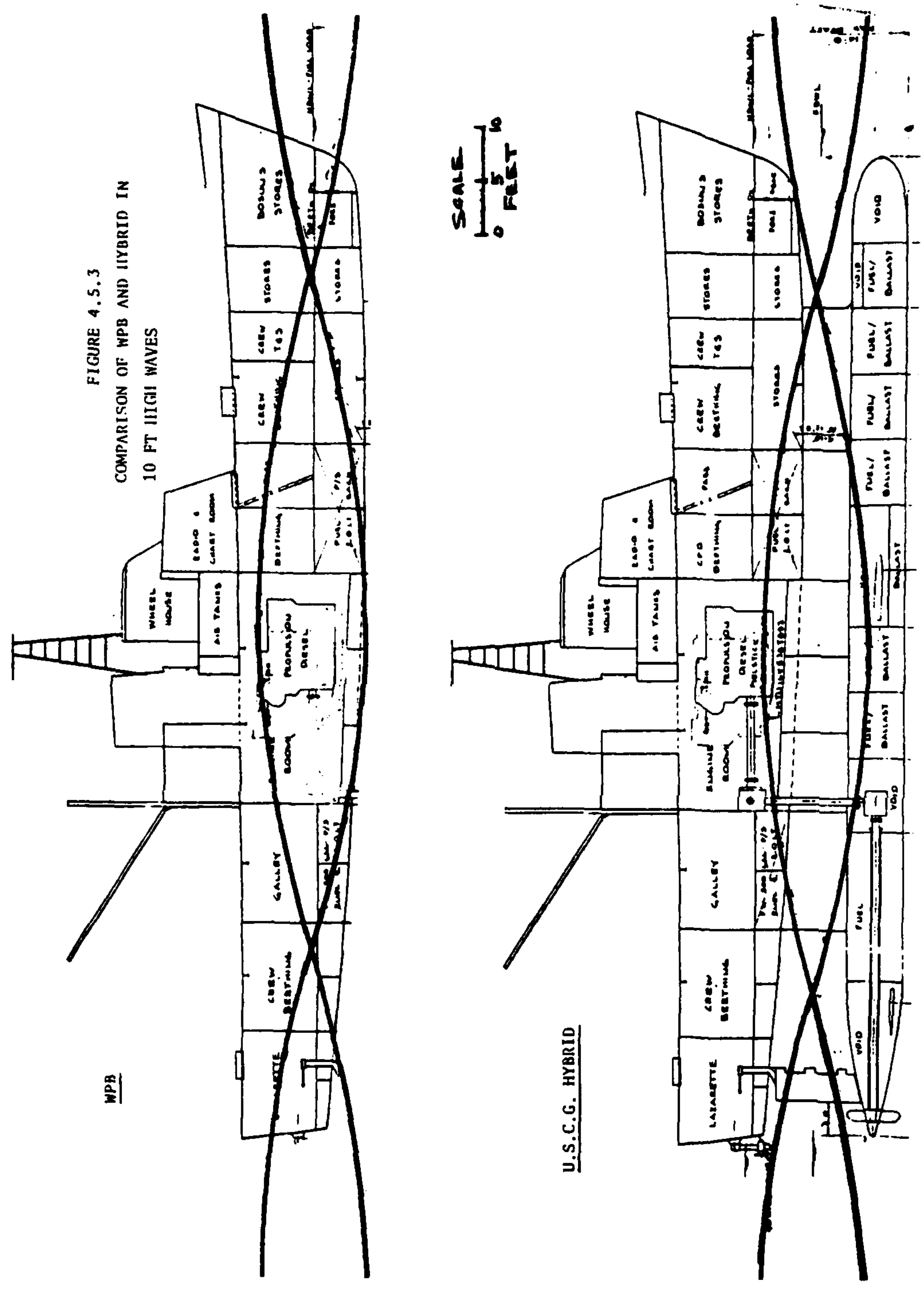


Figure 4.5-3. COMPARISON OF WPB AND HYBRID IN 10 FT HIGH WAVES

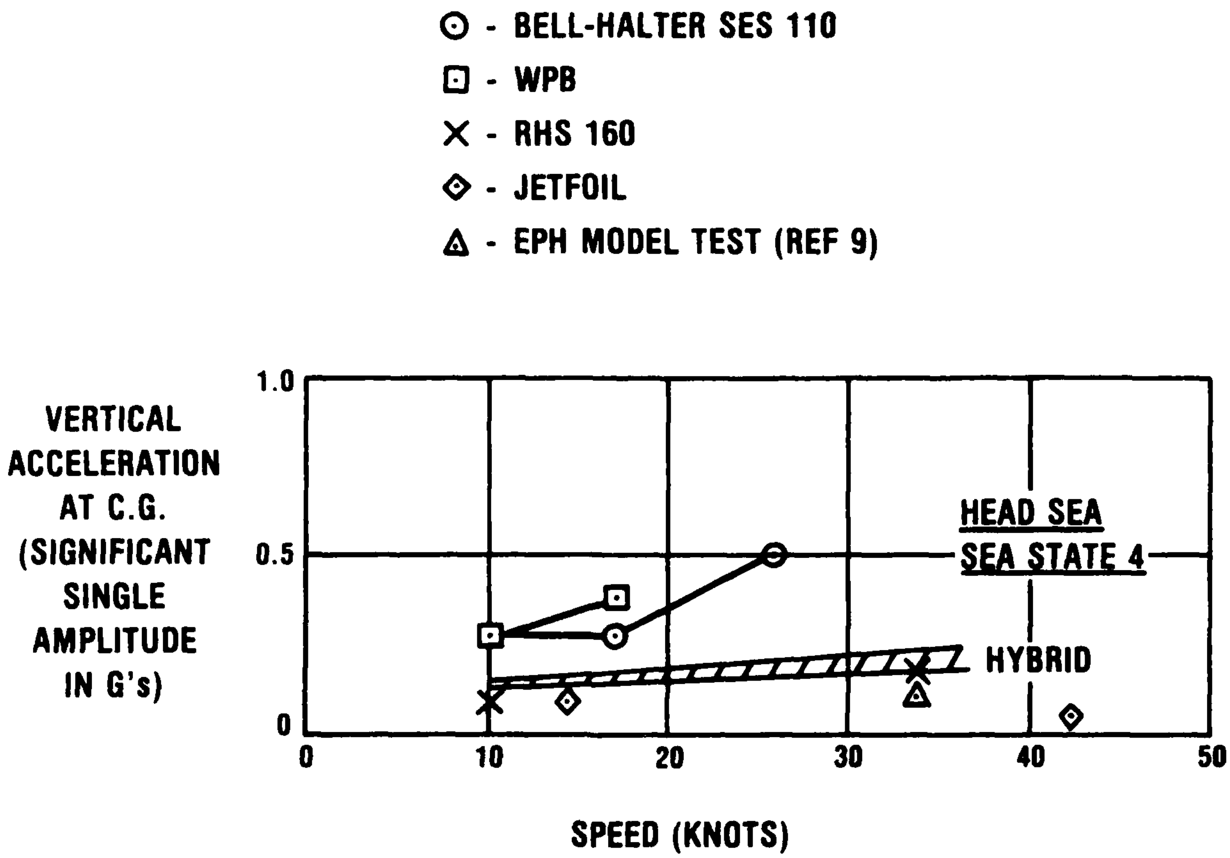


Figure 4.5-2. VERTICAL ACCELERATION COMPARISONS

SEA STATE 5 (10 FT SIGNIFICANT WAVE HEIGHT)

O - HIGHPOINT (PCH-1, MOD-1) TRIALS; 40 KNOTS; PILOT HOUSE

—— - HIGHPOINT (PCH-1, MOD-1) SIMULATION; 40 KNOTS; PILOT HOUSE

X - EPH MODEL TESTS, 33 to 42 KNOTS (REF 9)

X_B = AT BOW

$X_{C.G.}$ = AT CENTER OF GRAVITY

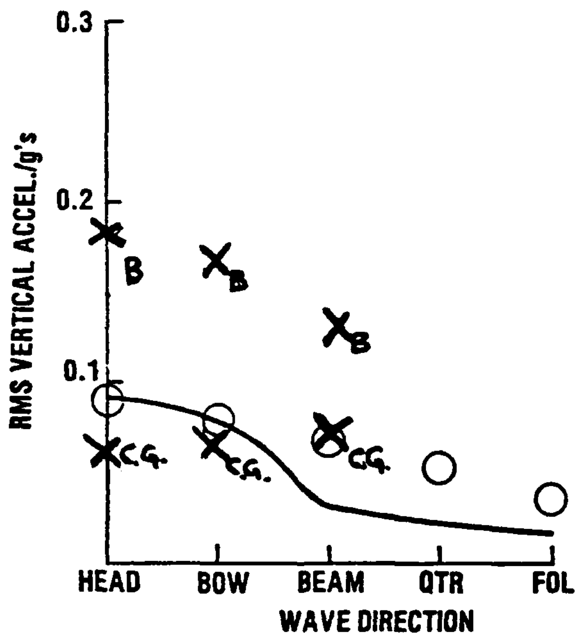


Figure 4.5-1. COMPARISON OF PCH-1 AND EPH VERTICAL MOTIONS

undetermined, elastic material or spring wire to assist in collapsing the bladder during the discharge procedure.

No bladder is provided in tank No. 8 because of the shaft tube installation.

The capacity of the buoyancy/fuel tank was derived as shown on Table 5-3. As noted therein, the total tank/strut/foil buoyancy is 89.38 long tons and the buoyancy to the foilborne waterline is 83.10 tons, of which 23.72 tons is contributed by void spaces.

An arbitrary figure of 10% of volume has been used for both the amount of ballast trapped between the tank structure and the bladder and also the amount of fuel remaining in the folds of the bladder after discharge.

As no bladder is installed in tank No. 8, the unusable fuel deduction has been reduced to 2% of total volume for this compartment only.

The net result is that in the *fully loaded fuel condition* a total of 30.75 tons is contained in the B/F tank of which 28.34 tons is considered usable.

In a *fully ballasted* condition, assuming all useable fuel has been transferred to the hull tanks (9.77 tons of fuel) the weight of ballast would be 28.65 tons and there would be 2.37 tons of trapped fuel remaining in the cells.

Table 5-3

USCG HYBRID CONCEPT - CAPACITIES

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - CAPACITIES			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
EEH			5/7/84	1

B/F TANK - VOLUME OF DISPLACEMENT

FOREBODY (1/2 ELLIPSOID) $V = \frac{4}{3}\pi abc/2$

$V = (\frac{4}{3}\pi \cdot 8 \cdot 2.5 \cdot 3.5)/2$ = $146.61\ ft^3$

MIDBODY AREA: $5.0^\phi + (2 \times 5.0) = 29.6\ ft^2$

$V = 29.6 \times 68.0$ = 2012.80

AFTERBODY (PARABOLOID) $V = \frac{1}{2}\pi r^2_{(AVG)} h$

$V = \frac{\pi}{2} \cdot 3^2 \cdot 14$ = 197.92

TOTAL TANK VOLUME = $2357.33\ ft^3$

BUOYANCY

TANK = 2357.33/35 = 67.35 LT

STRUT (TOTAL TO HULL) = 646.38/35 = 18.47

FWD FOIL = 3.05

AFT FOIL = 0.51

TOTAL TANK/STRUT/FOIL BUOYANCY: 89.38 LT

BUOYANCY TO 7.75' F.B.W.L. = 89.38 − 6.28 = 83.10 LT

SECTIONS UNAVAILABLE FOR FUEL/BALLAST

FOREBODY	$146.61\ ft^3$
MID-BODY FOIL ATTACH	285.70
PROP. GEAR BOX COMP.	199.80
AFTERBODY FOIL ATTACH	197.92
	$830.03\ ft^3$

VOID SPACE BUOYANCY = 830.03/35 = 23.72 LT

Table 5-3

USCG HYBRID CONCEPT - CAPABILITIES (Continued)

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT- CAPACITIES		
ANALYST: EEH	CHECKER:	ANALYSIS DATE: 5/7/84	PAGE NO. 2

TANK CAPACITY DERIVATION - FULL FUEL CONDITION

TANK	① GROSS VOLUME ft³	② 10% TRAPPED BALLAST ft³	③ TOTAL FUEL ①-② ft³	④ 10% UNUSABLE FUEL (EST) ft³	⑤ AVAILABLE FUEL ③-④	⑥ WT OF TRAPPED BALLAST ②/35
1	160.8	16.1	144.7	14.5	130.2	.46
2	175.7	17.6	158.1	15.8	142.3	.50
3	177.6	17.8	159.8	16.0	143.8	.51
4	177.6	17.8	159.8	16.0	143.8	.51
5	51.2	—	—	—	—	—
6	177.6	17.8	159.8	16.0	143.8	.51
7	177.6	17.8	159.8	16.0	143.8	.51
8	379.1	—	379.1	2% 7.6	371.5	—
TOTALS	1477.2	104.9	1321.1	101.9	1219.2	3.0

TANK	⑦ WT OF FUEL TOTAL ③/43	⑧ TOTAL WEIGHT OF LIQUID ⑥+⑦	⑨ WT OF USABLE FUEL ⑤/43	⑩ BALLAST TK WT ①/35	⑪ MAX LIQUID WT ⑨+⑩
1	3.37	3.83	3.03	—	3.03
2	3.68	4.18	3.31	—	3.31
3	3.72	4.23	3.34	—	3.34
4	3.72	4.23	3.34	—	3.34
5	—	—	—	1.46	1.46
6	3.72	4.23	3.34	—	3.34
7	3.72	4.23	3.34	—	3.34
8	8.82	8.82	8.64	—	8.64
TOTALS	30.75	33.75	28.34	1.46	35.21

Table 5-3

USCG HYBRID CONCEPT - CAPABILITIES (Continued)

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT- CAPACITIES		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
BBH		5/8/84	3

TANK CAPACITY DERIVATION - FULL BALLAST COND.

TANK	① GROSS VOLUME ft³	10% ② TRAPPED FUEL ft³	③ BALLAST VOL. ①-②	④ WT OF FUEL (TRAPPED) ②/43	⑤ WT OF BAL-LAST ③/35	⑥ TOTAL WT OF LIQUID ④+⑤
1	160.8	14.5	146.3	.34	4.18	4.52
2	175.7	15.8	159.9	.37	4.57	4.94
3	177.6	16.0	161.6	.37	4.61	4.98
4	177.6	16.0	161.6	.37	4.61	4.98
5	51.2	—	51.2	-	1.46	1.46
6	177.6	16.0	161.6	.37	4.61	4.93
7	177.6	16.0	161.6	.37	4.61	4.93
8	379.1	2% 7.6	—	.18	—	.18
	1477.2	101.9	1003.8	2.37	28.65	31.02

SECTION 6

PROPULSION OPTIONS

6.0 Existing Power Plant

The existing diesel propulsion plant for the WPB consists of two Detroit Diesel 16V149TI diesel engines rated at 1200 SHP each at 1800 RPM. As the initial DTNSRDC drag analysis indicated a horsepower requirement in the neighborhood of 6000 hp at 35 knots, it was obvious that the existing power plant would not suffice.

6.1 Propulsion Options

Initially, several options presented themselves:

(a) Diesel prime mover, normal conducting electric propulsion (liquid cooled)

(b) Gas turbine prime mover, normal conducting electric propulsion (liquid cooled)

(c) Gas turbine prime mover, mechanical transmission

(d) Diesel prime mover, mechanical transmission

(e) Gas turbine prime mover foilborne, diesel prime mover hullborne, mechanical transmission

(f) Gas turbine prime mover foilborne, diesel prime mover hullborne, electric propulsion

After a preliminary overview of the various options, the decision was made at the initial design review to restrict further investigation to full diesel prime movers and mechanical transmission.

Electric drive was initially eliminated from consideration due to the general unavailability of components and the excessive weight and bulk of those available from Alsthom Atlantique, the only apparent source. While Westinghouse, General Electric and AiResearch were all contacted, only AiResearch was able to supply specific information for the horsepower range

required. The letter and proposal forwarded by them is included as Attachment 1 to this section. A cursory perusal of the information would tend to indicate that, while perhaps not for the M174, there is considerable potential for this type of propulsion in the future. While the unit weights may still pose a problem, the fact that the ships service generators would be eliminated partially compensates for it. The U.S. Navy electric propulsion R&D program should be monitored as to progress and possible applicability to this Hybrid Concept.

6.2 Power Plant Comparisons

Due to space and weight limitations on board the WPB the selection of candidate engines was constrained. After a review of all major manufacturers, both in the USA and abroad, there appeared to be only two diesel engines having the required qualifications. They were the SEMT Pielstick 12PA4200-VGDS and the MTU 16V538TB92. Two other Pielstick engines (of a different series) the 16 and 18 cylinder PA4200-VG (with a reduced height) incurred too great a weight penalty to be considered (see Table 6-1).

Initially the Pielstick engine was favored over the MTU for two reasons - the height was less and the exhaust manifold connections were on the aft end instead of the top as shown on the MTU thumbnail layouts. This, coupled with the fact that MTU detail information was not received for some time after receipt of the Pielstick, led all calculations and drawings to be prepared for a Pielstick installation.

However, upon receipt of the MTU information, it was apparent that the exhaust manifolds were considerably below the highest point of the engine and that by shifting the engines aft about 30 inches the exhaust would align with the uptakes, thereby eliminating the reverse bends required for the Pielstick exhausts. The installation of the MTU's would also result in a weight savings of only 0.6 tons, and their additional width would make for a more cramped engine room. The outline of the MTU is shown superimposed over the Pielstick on Figure 3-1.

Table 6-1

CANDIDATE ENGINE COMPARISONS

	MTU 16V538TB92	PIELSTICK PA4200-VG 18 Cylinders	PIELSTICK PA4200-VG 16 Cylinders	PIELSTICK 12PA4200VGDS
HP Cont	3410 @ 1710 RPM	3295 @ 1475 RPM	2930 @ 1475 RPM	3000 @ 1500 RPM
HP Max	4080 @ 1790	3600	3200	3300 @ 1550
L, inches	124.4	134.9	123.1	117.1
W, inches	64.6	66.9	66.9	57.1
H, inches	90.75	73.4	73.4	84.8
WT, Dry	6.6 LT	8.5 LT	7.6 LT	6.9 LT

Presently Installed - DDA16V149TI

1120 SHP @ 1800 RPM
L = 98 inches
W = 63 inches
H = 65 inches
WT = 7.3 LT

DDA570KA Gas Turbine

H Cont	6445*
H Max	7170*
L	70.2 inches
W	31.6 inches
H	36.1 inches
WT	1350 lbs.
SFC	.460
RPM	6000 - 12000

*Mfg. rating at 59° F.

If the gas turbine was to be considered it would necessitate relocating one diesel engine to the centerline with the existing generators moved to one side and the turbine located on the other side to maintain transverse center of gravity at the centerline.

A comparison of all engines considered is given in Table 6-1. The engine performance has previously been covered in Section 4.3. Dimensional sketches of the two leading candidates are shown in Figures 6-1 and 6-2.

6.3 Transmission

The transmission proposed for the M174 is an adaptation of the proven Grumman design developed for the "Flagstaff" and refined for use on the Design M161 as described in reference 15. As the overall shaft speed reduction is only 1.5:1, it is recommended that the total reduction be taken in the lower bevel gear box in order to keep the three upper hull boxes and the associated shafting as small and light as possible.

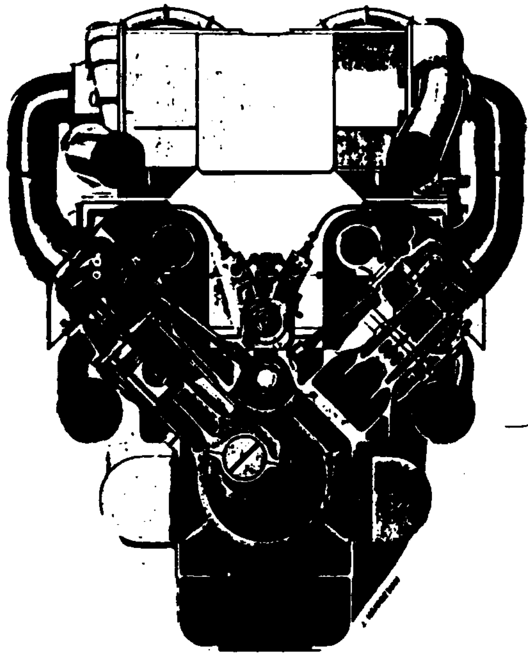
The arrangement of the major components is shown on Figure 6-3. The lower bevel gear box and the foil mount are contained in dedicated dry compartments. The propeller shaft is enclosed in a shaft tube fitted with sleeve bearings and a shaft seal at the forward end. As the propeller is of fixed pitch, it is attached to the shaft in a conventional manner.

6.4 Auxiliary Propulsion

Propulsive redundancy will require an auxiliary propulsion unit. Inasmuch as each generator is rated at only 30kw, available power is minimal and therefore it appears that a 40 HP outdrive powered by either an electric or hydraulic motor would be the maximum accommodated. Based upon hullborne drag calculations a speed of approximately 5 knots might be obtained.

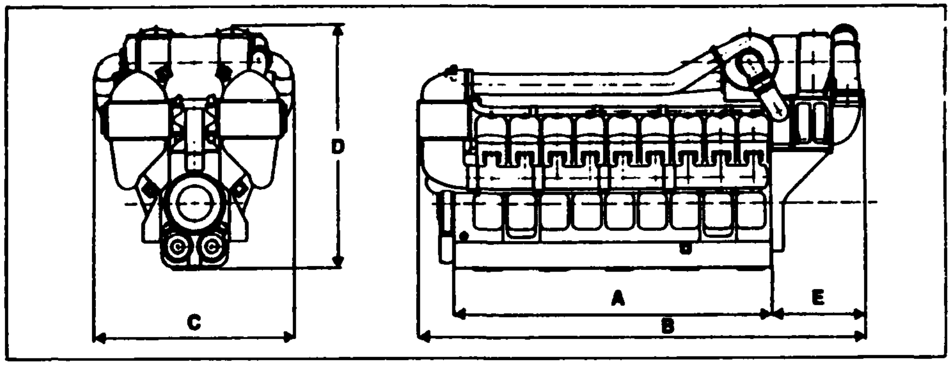
As an alternate, a dedicated 4 cylinder engine of about 150 HP with outdrive may be installed in the lazarette since the weight penalty can probably be accepted. This would increase the hullborne speed to about 8 knots.

MOTEUR
PA4 200 - VGDS



Coupe Transversale
Cross Section

Encombrement/Overall dimensions



Dimensions moteur mm Engine Dimensions mm	A	B	C	D	E	Poids (kg) Weight (kg)
8 cyl.	1.405	2.578	1.576	2.225	850	5.100
12 cyl.	2.005	2.973	1.450	2.155	645	7.000
16 cyl.	2.605	3.795	1.850	2.225	850	9.120
18 cyl.	2.905	4.095	1.850	2.225	850	10.020
20 cyl.	3.250	4.395	1.850	2.225	850	11.700

Performances

Puissance mini. continue (72 ch) Mini. continuous rating (72 HP)	Puissance maxi continue maxi. continuous rating	Puissance intermittente intermittent rating	Puissance de pointe sprint rating
à 450 tr/min 6,9 ch/cyl. ou 5,1 kW/cyl. at 450 r.p.m. 6.9 HP/cyl. or 5.1 kW/cyl.	à 1 500 tr/min 250 ch/cyl. ou 184 kW/cyl. at 1,500 r.p.m. 250 HP/cyl. or 184 kW/cyl.	à 1 550 tr/min 275 ch/cyl. ou 202 kW/cyl. at 1,550 r.p.m. 275 HP/cyl. or 202 kW/cyl.	à 1 595 tr/min 300 ch/cyl. ou 221 kW/cyl. at 1,595 r.p.m. 300 HP/cyl. or 221 kW/cyl.

Technical characteristics are given in this brochure for information. They are subject to change

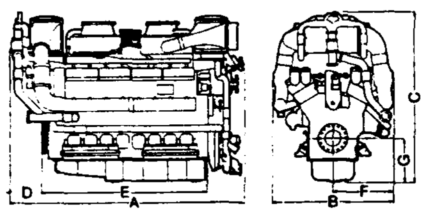
Figure 6-1. PIELSTICK PA4200-VDGS DIESEL ENGINE

General Specifications

		12 V 538 TB 91	12 V 538 TB 82/92	16 V 538 TB 91	16 V 538 TB 82/92	20 V 538 TB 91	20 V 538 TB 82/92
No. of cylinders		12		16		20	
Vee arrangement		60°					
Bore and stroke	mm	185/200					
Swept volume, cylinder	liters	5.30					
Swept volume, total	liters	64.5		86.0		107.5	
Compression ratio		15,0	14,0	15,0	14,0	15,0	14,0
Direction of rotation		c.c.w.					
Cooling method		two-circuit system, closed engine water circuit					
Injection method		precombustion chamber					
Mode of supercharging		1 exhaust turbocharger		2 exhaust turbochargers			
Intercooling		1 intercooler		2 intercoolers			
Starting method		air-in-cylinder (1 cylinder bank)					
Cylinder heads		individual heads					
No. of valves per cylinder		3 inlet, 3 exhaust					
Pistons		composite pistons (steel crown, light alloy skirt)					
Piston cooling method		oil cooling through telescoping tubes					
Crankshaft		disc-webbed crankshaft, roller bearings					
No. of main bearings		7		9		12	
Camshafts		overhead type					
Injection pump		unit injectors					
Engine oil capacity	(approx.) liters	270		305		380	
Cooling water capacity	(approx.) liters	210		290		450	

Dimensions and Weights

Dimensions in mm



	12 V 538 TB 91	12 V 538 TB 82/92	16 V 538 TB 91	16 V 538 TB 82/92	20 V 538 TB 91	20 V 538 TB 82/92
A	2545		3220	3160	3800	3800
B	1640		1640	1640	1640	1640
C	2230		2305	2305	2320	2320
D	220		450	450	410	340
E	1820		2265	2265	3190	3230
F	820		820	820	820	820
G	760		595	595	665	665
Weight kg[1]	5200	5150	6750	6700	9080	9000

[1]) basic engine, dry weight

Ratings

Application	Application Group	Speed RPM		Ratings (kW, HP)											
						12 V 538 TB 82				16 V 538 TB 82				20 V 538 TB 82	
Marine Propulsion	1 D	1710	1)			1630	2215			2185	2970			2730	3715
		1760	2)			1780	2420			2380	3240			2980	4050
				12 V 538 TB 91		12 V 538 TB 92		16 V 538 TB 91		16 V 538 TB 92		20 V 538 TB 91		20 V 538 TB 92	
	1 DS	1790	1)	1690	2300	1880	2555	2260	3060	2510	3410	2815	3840	3135	4265
		1850	2)	1860	2530	2080	2830	2490	3390	2770	3770	3110	4230	3460	4705
		1900	3)	2020	2750	2250	3060	2690	3660	3000	4080	3370	4580	3750	5100

Explanations

Ratings	1) Continuous power ISO 3046/I 2) Overload power ISO 3046/I (2 hours within 12 operating hours) 3) Maximum power (½ hour within 6 operating hours)	
Application Groups	1 D:	Passenger vessels in seasonal service, cruising yachts, patrol boats, *cruising engines of* combined propulsion plants, high-performance operation vessels (S.A.R.), hydrofoils[1]
	1 DS:	High-speed yachts, FPBs, and special-purpose craft
Reference Conditions	1 D/1 DS:	Intake air temperature 27° C, charge air coolant temperature 27° C, barometric pressure 1000 mbar

[1] exact power rating dependent on project.

MTU OF NORTH AMERICA, INC.
1 East Putnam Ave.
GREENWICH, CONNECTICUT 06830
(203) 629-4300 Telex 64-3412

Subject to modifications in the interest of technical progress.

Figure 6-2. MTU 16V538 TB92 DIESEL ENGINE

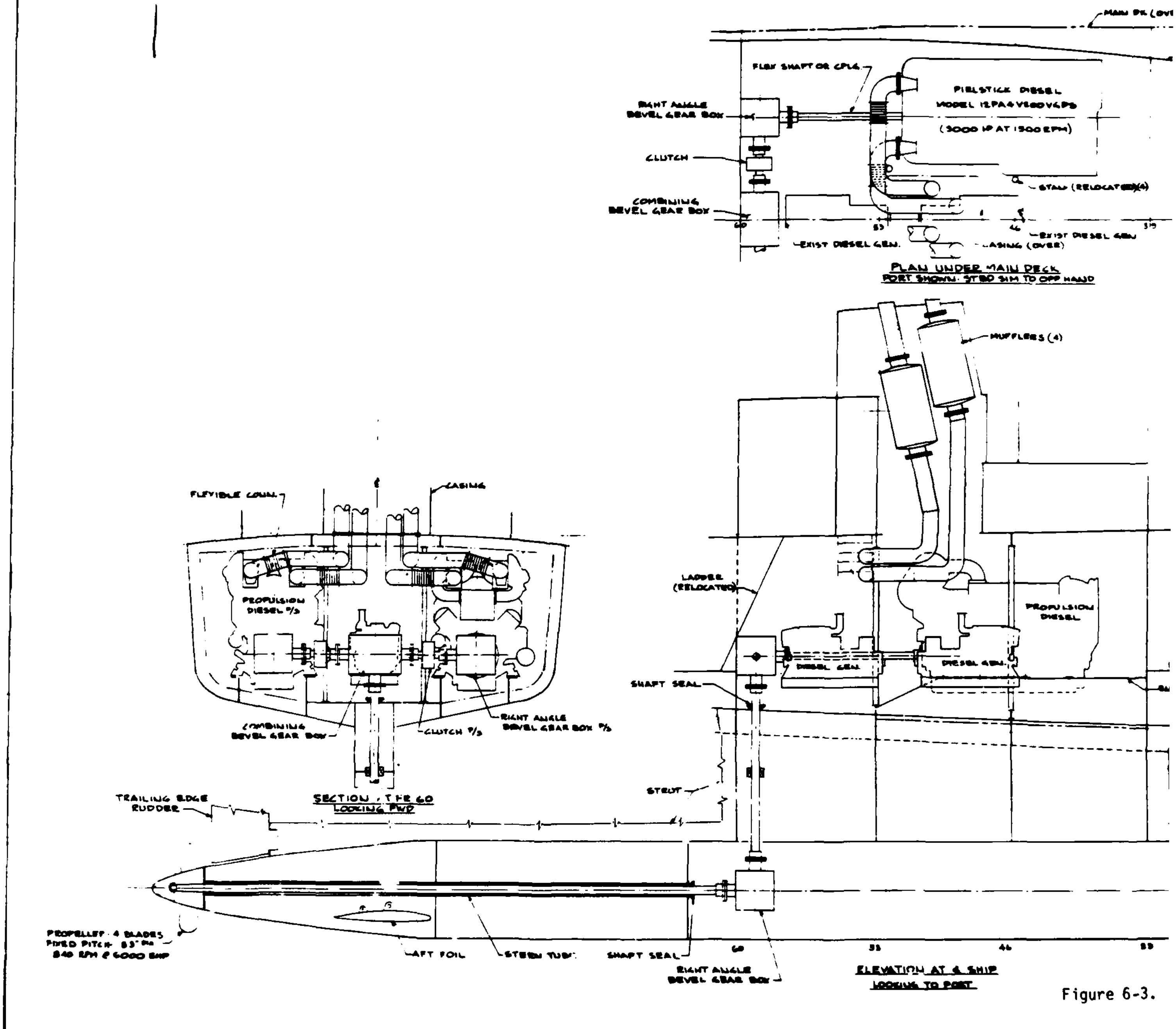

FLEX SHAFT OR CPLG.
RIGHT ANGLE BEVEL GEAR BOX
CLUTCH
COMBINING BEVEL GEAR BOX
PIELSTICK DIESEL
EXIST DIESEL GEN.
PLAN UNDER MAIN DECK
PORT SHOWN. STBD SIM TO OPP HAND
MUFFLERS (4)
FLEXIBLE COUPL.
CASING
PROPULSION DIESEL P/S
COMBINING BEVEL GEAR BOX
CLUTCH P/S
RIGHT ANGLE BEVEL GEAR BOX P/S
SECTION - T FR 60 LOOKING FWD
TRAILING EDGE RUDDER
LADDER (RELOCATED)
SHAFT SEAL
STRUT
PROPULSION DIESEL
DIESEL GEN
AFT FOIL
STERN TUBE
SHAFT SEAL
RIGHT ANGLE BEVEL GEAR BOX
ELEVATION AT ℄ SHIP LOOKING TO PORT

Figure 6-3.

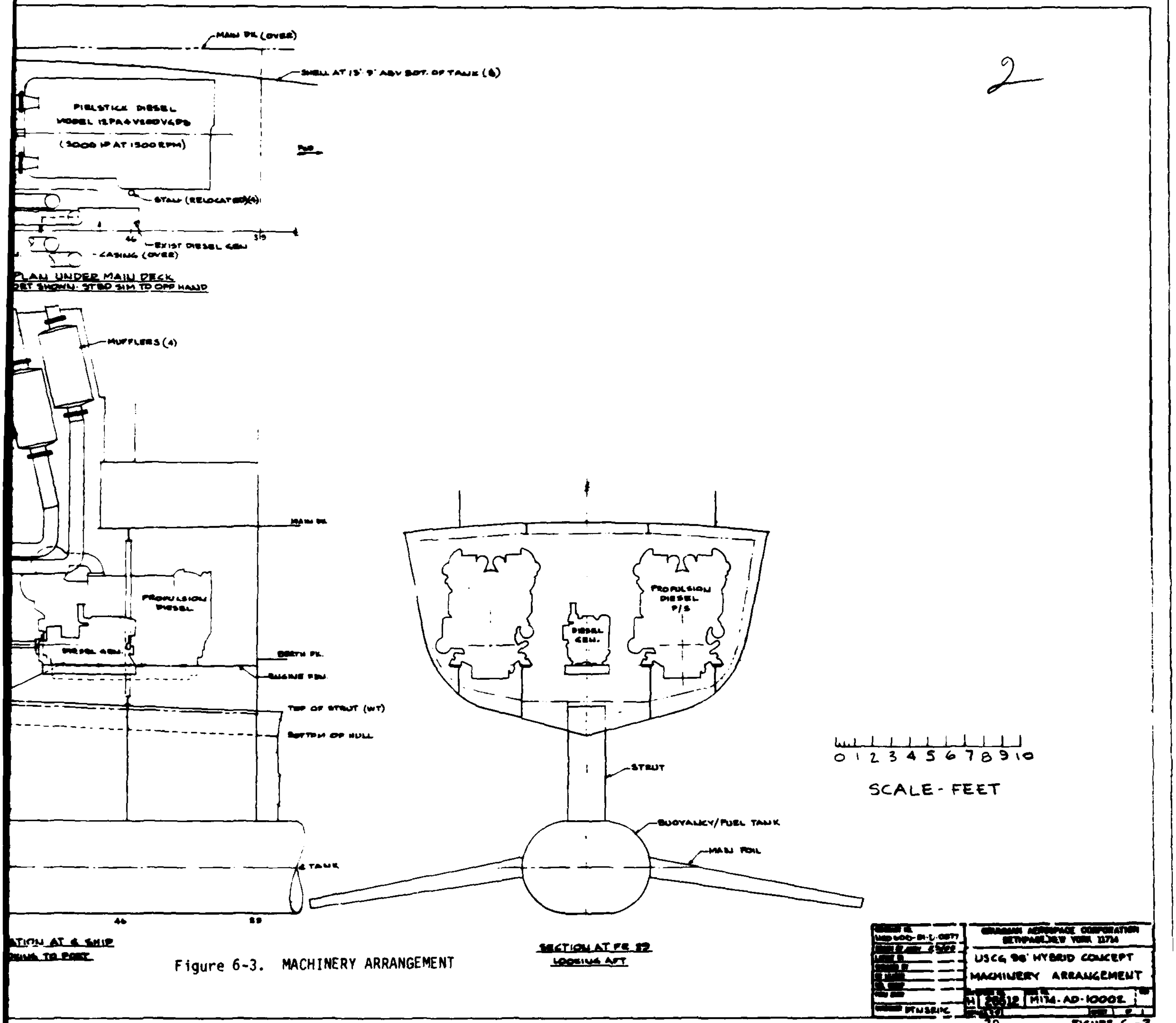


Figure 6-3. MACHINERY ARRANGEMENT

ATTACHMENT 1

AiResearch Manufacturing Company
A Division of The Garrett Corporation
2525 W 190th ST
TORRANCE
CALIFORNIA 90509
Tel (213) 323-9500/321-5000
Twx 910-346-6729 Telex 67-4490

In reply refer to:
49307-49400-006

April 10, 1984

Mr. Edward Hermanns
Grumman Aerospace Corporation
Marine Department
MS ALL-04
Bethpage, New York 11714

Via: John Gentilella
The Garrett Corporation
1 Huntington Quadrangle
Suite 4S04
Melville, New York 11747

Dear Mr. Hermanns:

Subject: 5000 Shp Marine Propulsion System for Hydrofoil Cutter

Enclosure (1) provides preliminary data for an electric propulsion system capable of meeting your requirements for a single-screw propulsion system using two 1500 rpm diesel engines to provide 5000 shp input to the propeller at 900 rpm propeller speed.

The enclosures show that the weight of the propulsion system is estimated to be 56,850 lbs and that the propulsion system has an overall efficiency of 89 percent when developing 5000 shp propulsion output and delivering 100 kW of power to the ship service system.

We hope that the preliminary information provided in this letter will permit you to further evaluate the application of electric propulsion to the hydrofoil cutter.

Please contact us if you require any additional assistance.

Sincerely,

A. K. Smith

A. K. Smith
Marine Systems Engineering
Rapid Transit & Electrical
Power Systems

AKS/dp

Enclosure

Enclosure (1)

5000 SHP MARINE PROPULSION SYSTEM FOR HYDROFOIL CUTTER

Figure 1 shows a single line diagram of proposed single screw propulsion system. The system is comprised of the components as defined in Table 1. The total system weight is estimated to be 56,850 lbs. This low system weight results from the selection of a high-speed liquid-cooled propulsion motor with an epicyclic reduction gear output to the propeller.

Generators are direct-driven by the 1500 rpm diesel engines and are identical to the motor except for series connected windings in the generator and parallel connected windings in the motor. The generators are excited from brushless rotating rectifier exciters integrated with the generators, and the motor is excited from a static exciter via slip rings on the motor shaft. All machines are oil cooled to minimize size and weight and to provide isolation of the windings from the marine environment.

Switching is provided by compact light-weight vacuum contactor modules distributed throughout the system.

The motor is driven by a dc link power converter which provides adjustable motor speed control from zero to full ahead or reverse from a constant voltage and constant frequency propulsion bus. This bus provides 50 Hz 375 volt, 3-phase power to the ship service system via a transformer. A solid-state converter can be provided to supply 60 cycle loads where the loads must operate at 60 Hz. The bus also provides power to the motor static exciter.

Bypass contactors are provided around the converter to permit operation of the ship at propeller speeds up to 50 percent of rated directly from the output of either generator. In this mode of operation, the generator supplying the motor directly must provide output voltage proportional to motor speed.

The capability of the system to provide propulsion derived ship service power permits efficient supply of energy to the ship service load with a minimum of equipment.

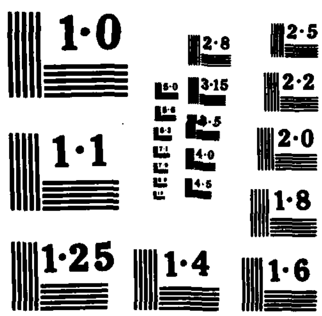
The performance of the system at 5000 shp output plus 100 kW delivered to the ship service electric system is estimated as follows:

. Propulsion Power Output	3730 kW
. Reduction Generator Efficiency	.985
. Motor Output	3786 kW
. Motor Efficiency	.975
. Motor Input	3884 kW
. Converter Efficiency	.985
Total Propulsion Load	3940 kW
. Motor Excitation	75 kW
. Static Exciter and Transformer Efficiency	.96
Excitation Load	78 kW
. Ship Service Output	100 kW
. Transformer Efficiency	.97

AD-A156 710 US COAST GUARD HYBRID CONCEPT(U) GRUMMAN AEROSPACE CORP BETHPAGE NY C HERMANNS ET AL. AUG 84 USCG-D-6-85 DTCG23-84-F-20024 2/2

UNCLASSIFIED F/G 13/10 NL

END
DATE
FILMED
8 85


1·0
2·8
2·5
3·15
2·2
2·0
1·1
4·0
4·5
1·8
1·25
1·4
1·6

Ship Service Load		103 kW
Total Generator Output		4121 kW
. Generator Efficiency		.975
. Total Generator Input		4226 kW
. Total Generator Excitation		74 kW
Total Diesel Load		4300 kW
System Efficiency	$\frac{5000 \times .746 + 100}{4300}$	0.8913
Diesel Output per Diesel		2880 hp

These preliminary estimates of the weight, size, and performance of an electric propulsion system with propulsion derived ship service power are based on our studies of performance that can be expected from near-term advanced electric machinery, switchgear, power converter, and reduction gear designs. It is estimated that such equipment can be designed, fabricated, and delivered in approximately 36 months after start of detail system design.

A direct-drive motor operating at 900 rpm is estimated to weight 32,500 pounds, be 115 inches long, and have a diameter of 66 inches. This is 20,500 pounds greater than that of the high speed motor and 19,750 pounds greater than that of the high speed motor and gearbox. It, therefore, appears desirable to accept the reduction gear losses to realize this weight savings.

Air-cooled machinery would be larger in diameter and length and is estimated to be 50 to 100 percent greater in weight than the liquid-cooled machines described herein.

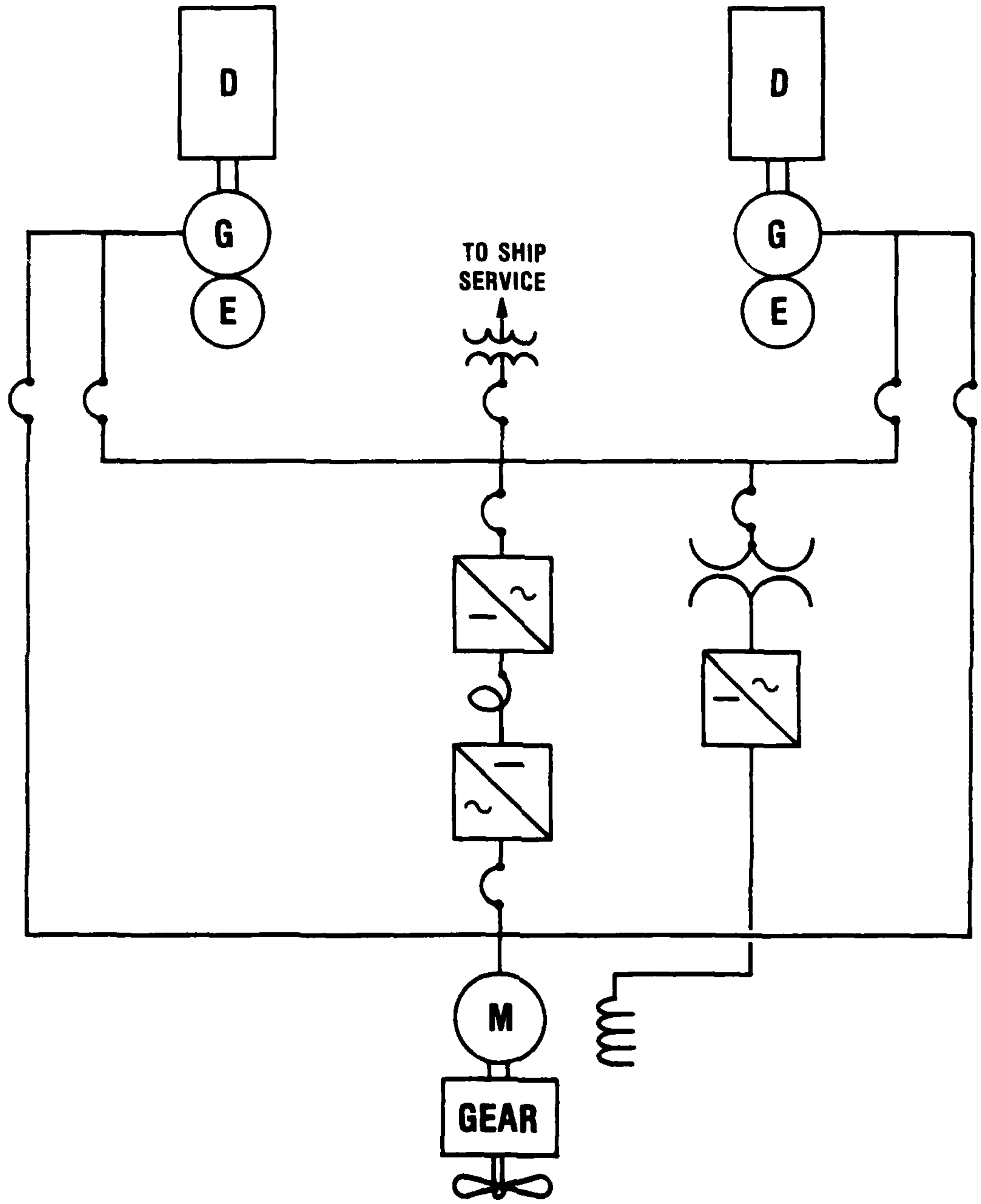


FIGURE 1 SINGLE LINE DIAGRAM

TABLE 1 ELECTRIC DRIVE COMPONENT LIST

Item	Description	Qty/ Shipset	Length (In.)	Width (In.)	Height (In.)	Unit Weight (Lbs)	Shipset Weight (Lbs)
1	**Main Propulsion Motor** 5125 hp, 3000 rpm, 2300 volt, 0.8 power factor, 1200 ampere, 3-phase, 4-pole nonsalient pole, oil-cooled synchronous machine with slip-ring excitation.	1	88	45	45	12,000	12,000
2	**Main Reduction Gear*** 5000 hp, 3000 rpm input, 900 rpm output epicyclic reduction gear. *Exclusive of thrust bearing	1	26	22	22	750	750
3	**Main Propulsion Generator** 2400 KVA, 1500 rpm, 2300 volt, 0.86 power factor, 600 amperes, 3-phase, 4-pole nonsalient pole, oil-cooled synchronous machine with brushless rotating rectifier exciter.	2	88	45	45	12,000	24,000
4	**Motor Static Exciter** 100 kW, 150 KVA, 6-phase phase-delay-rectifier with 2300 volt input transformer.	1	35	26	74	1,500	1,500
5	**Power Converter** Three-phase full wave thyristor bridge rectifier and inverter with smoothing inductor, protection, and controls. Oil cooled.	1	35	48	74	12,000	12,000
6	**Switchgear Modules** Three-phase, 2400 volt, 1200 ampere vacuum contactors, converter isolation.	2	25	20	20	300	600

TABLE 1 (CONT)

Item	Description	Qty/ Shipset	Length (In.)	Width (In.)	Height (In.)	Unit Weight (Lbs)	Shipset Weight (Lbs)
	Three-phase, 2400 volt, 600 ampere vacuum contactors, Converter bypass, generator output, ship service load, static exciter input.	6	26	20	20	250	1,500
7	Ship Service Electric Power Transformer Three-phase 2300/375 volt, 50 Hz, 100 KVA	1	32	22	45	1,000	1,000
8	Propulsion Plant Control Panel Contains generator voltage regulators, generator synchronizing controls, generator load control, generator speed control, switchgear control, converter controls, and integrated protection *and control functions.*	1	36	30	74	1,900	1,900
9	Cooling Module* Cooling system for motor, generators, and converter comprised of pumps, filters, strainers, oil-to-sea water heat exchangers, related instrumentation, and controls.	1	-	-	-	1,600	1,600
	*Weight does not include weight of sump tank and oil.						
						Total weight per shipset	56,850 lbs

SECTION 7

SYSTEMS

7.0 General

While the basic fuel and sea water systems are contained within the B/F tank and strut, they must of necessity be integrated with the existing craft systems to provide the fuel and ballast management required for both hullborne and foilborne operation. An elementary schematic of the new elements of the fuel and sea water systems is shown on Figure 7-1. Other systems requiring modification to varying degrees would be the lube oil, electrical, compressed air, tank vent, fresh water, steering, and hydraulic systems.

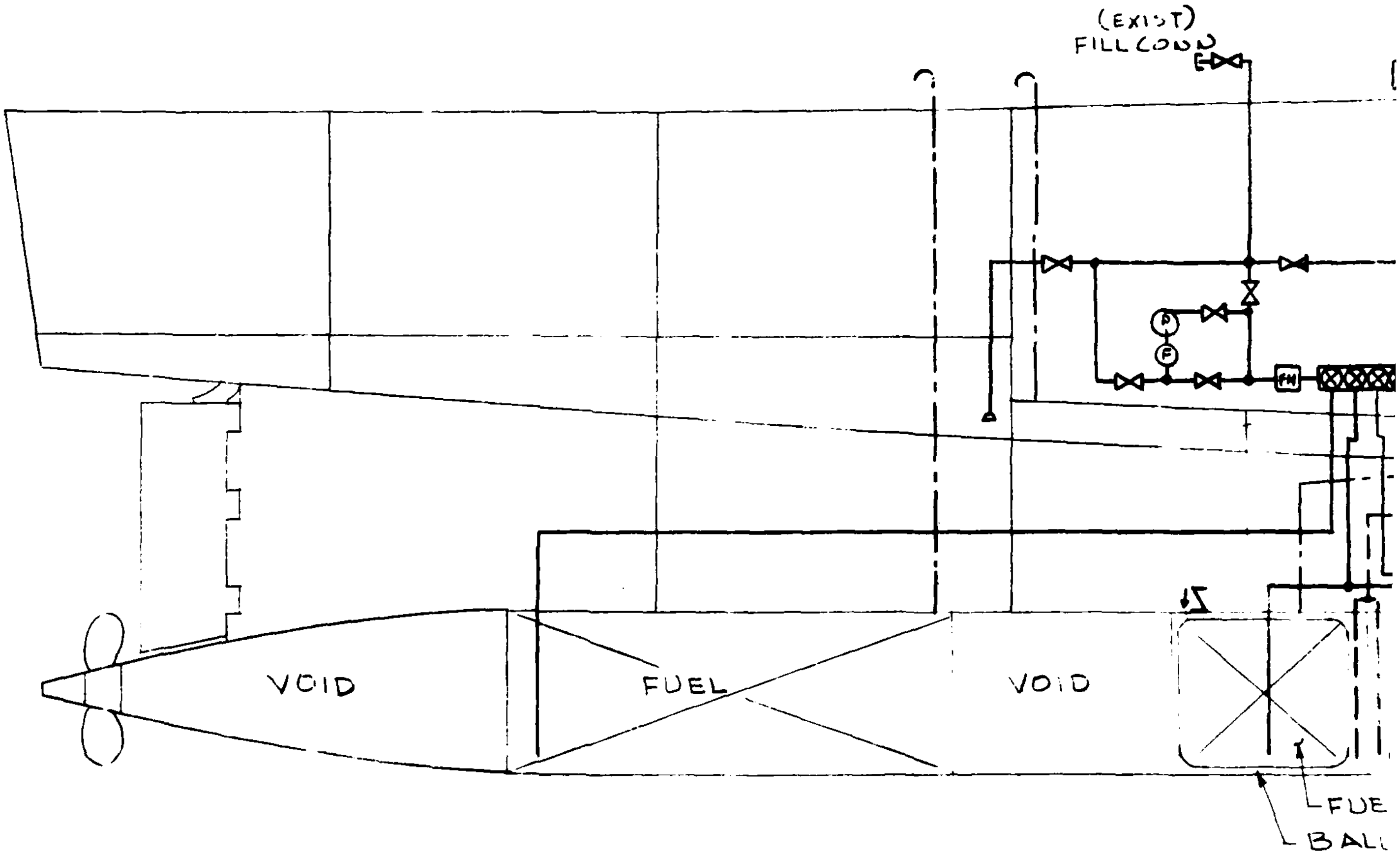
7.1 Fuel System

For piping simplification the fuel system within the B/F tank has been arranged in three groups of two cells and one dedicated fuel tank aft. The six cells have perforated fill/suction pipes integral with the bladders and are connected to headers within the strut which terminate at the management manifold in the engine room. The aft tank has a single full/suction line which leads directly to the manifold.

Additionally, a pump with associated valving, filters, and totalizing flow meters is to be installed for filling, discharging and transferring fuel between the B/F tank and the hull. This system would be interconnected at some convenient location to the existing fuel system.

All monitoring and control equipment should be grouped together, probably in the area formerly occupied by one of the main gear boxes.

It must be appreciated, however, that the existing fuel oil service system for the propulsion diesel appears undersized for the new engines as the available information indicates a fuel flow difference of two gpm. Depending upon a flow analysis, components of the existing system may require replacement.


(EXIST)
FILL CONN
VOID
FUEL
VOID

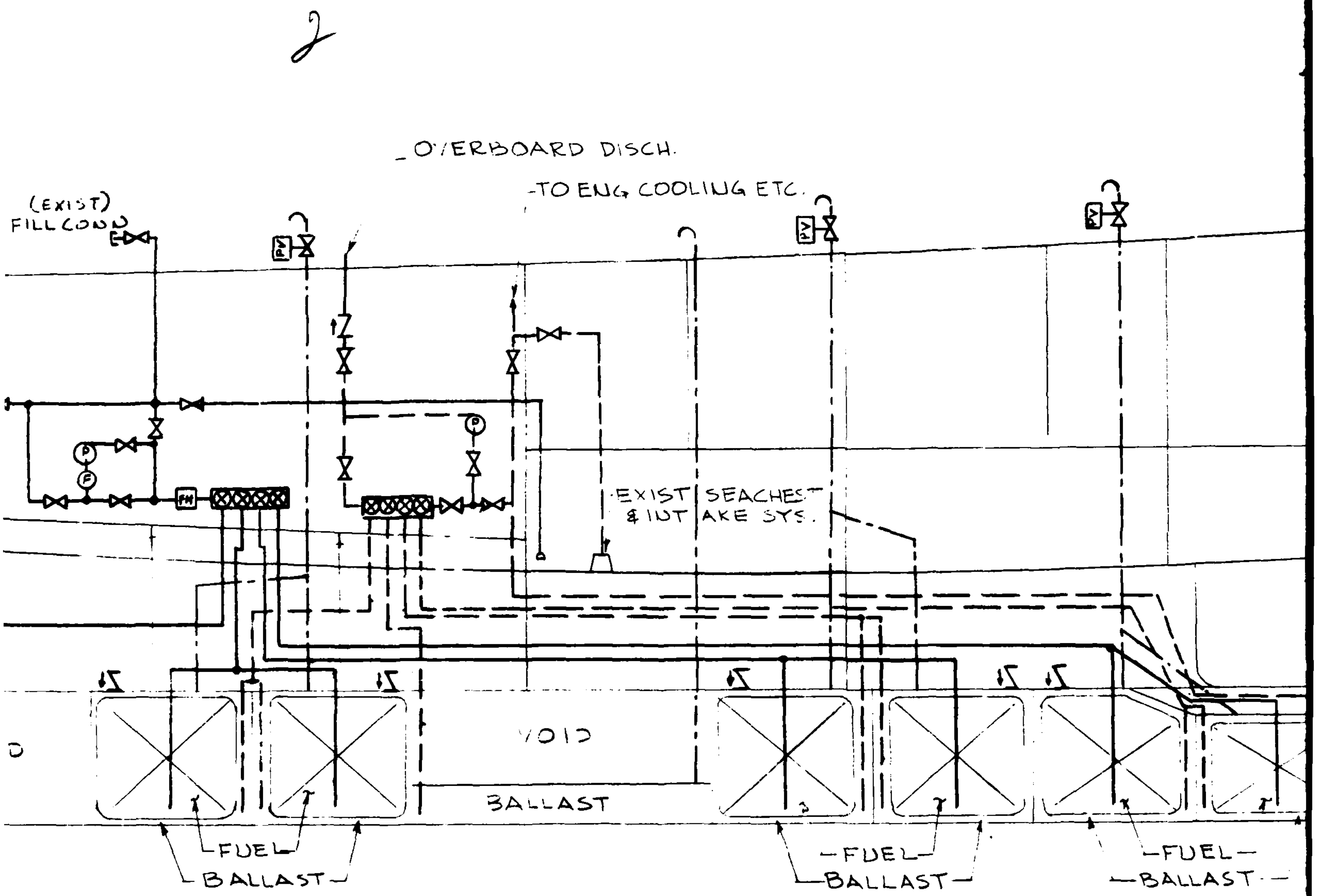

OVERBOARD DISCH.
TO ENG COOLING ETC.
(EXIST)
FILL CONN
EXIST SEACHEST
& INTAKE SYS.
VOID
BALLAST
FUEL
BALLAST
FUEL
BALLAST
FUEL
BALLAST

Figure 7-

3

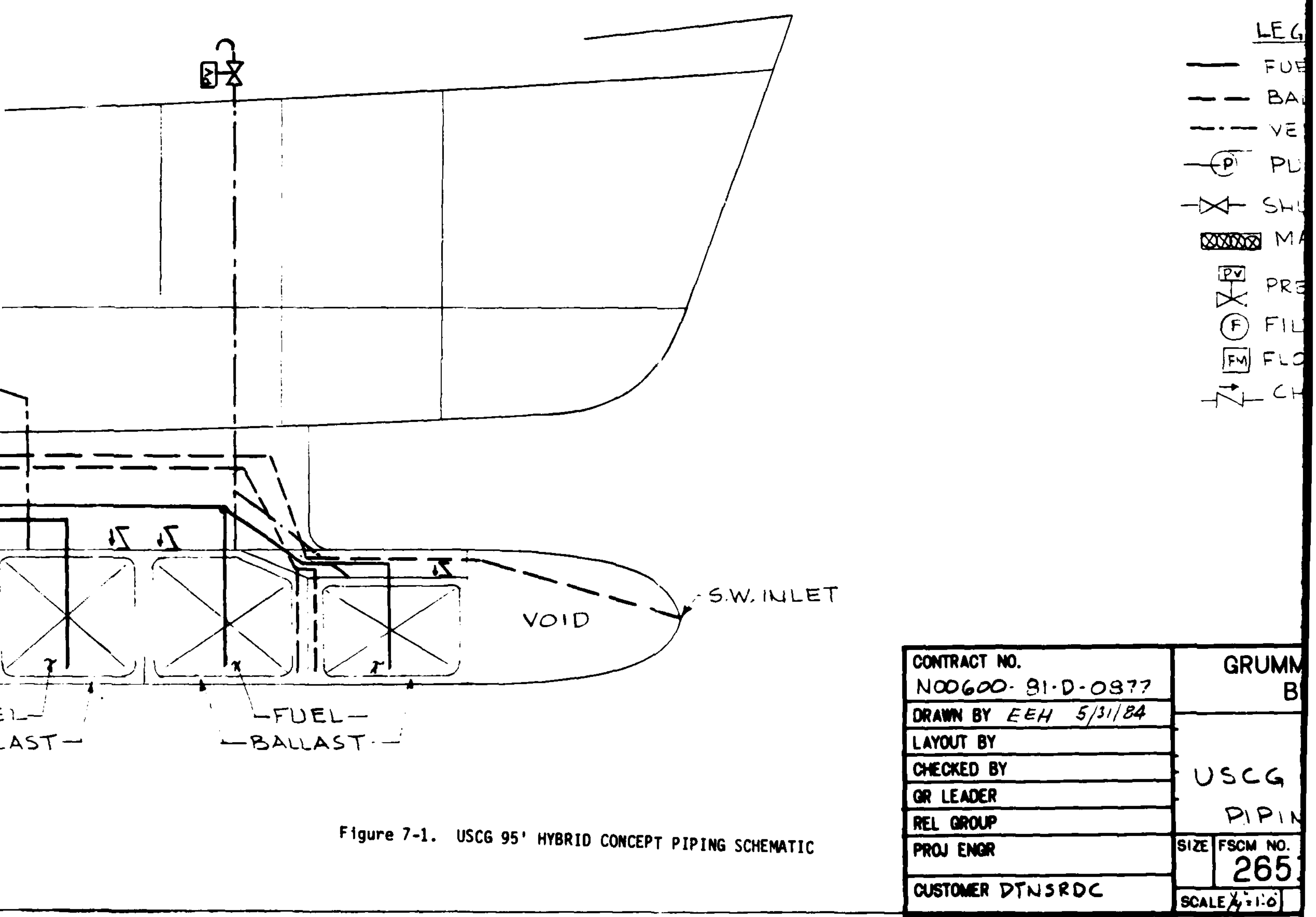


Figure 7-1. USCG 95' HYBRID CONCEPT PIPING SCHEMATIC

7

4

LEGEND

FUEL LINES

BALLAST LINES

VENT LINES

PUMP

SHUT-OFF VALVE

MANIFOLD

PRESSURE REG. VALVE

FILTER

FLOW METER

CHECK VALVE

NLET

MATIC

CONTRACT NO. N00600-81-D-0877	GRUMMAN AEROSPACE CORPORATION BETHPAGE, NEW YORK 11714		
DRAWN BY EEH 5/31/84	FIGURE 7-1 USCG 95' HYBRID CONCEPT PIPING SCHEMATIC		
LAYOUT BY			
CHECKED BY			
GR LEADER			
REL GROUP			
PROJ ENGR	SIZE	FSCM NO. 26512	DWG NO. M174-AD-10003 / REV
CUSTOMER DTNSRDC	SCALE 1/4"=1'-0"		SHEET 1 OF 1

For fuel flow monitoring and recording it is recommended that the NAP Commercial system as marketed by Electronic Marketing Systems of San Diego, California, Appendix D, be investigated. This system incorporates a tank level memory as well as programmable delivery quantities.

7.2 Sea Water System

In a similar manner, the six cells (outside of the bladders) are connected through headers to a manifold probably located in a similar location to the fuel manifold but on the opposite side of the craft.

To perform the function of the existing sea chests while foilborne, an intake pipe runs from the nose of the tank to a connection to the existing sea water system and also to the new ballast manifold. It is presumed that ram pressure will service the system while foilborne, but a pump must be included to assist in evacuating the cell areas as well as the dedicated ballast compartment below the forward foil mount.

As with the existing fuel system, the sea water service to the existing diesels is inadequate and replacements will probably be required for the components between the sea chests and the engine connections.

7.3 Fuel and Ballast Management

The contemplated interaction of these two systems would occur either foilborne or hullborne. The initial fuel fill of the tanks and cells would occur with air surrounding the bladders, and under the pressure fill, the air would be evacuated through the pressure regulator vents.

Subsequent fuel transfer would be accomplished through introducing ballast water into the ballast compartment of the cells, either by ram pressure or pump assisted, which would tend to force the fuel from the bladder into the hull tanks. To prevent the sea water from discharging through the vent pipes rather than squeezing the bladders, each vent is fitted with a pressure regulator set at a predetermined level.

Refueling would be similarly accomplished, the fuel pressure would force the ballast water out through the manifold to the overboard discharge.

7.4 Lube Oil System

The lube oil system for the new diesel engines would be self-contained, but an additional system must be provided to provide forced lubrication to the new gear boxes, both in the hull and in the B/F tank. The reservoir for this system could conceivably be located within the strut, thereby not affecting the center of gravity adversely.

7.5 Compressed Air System

The compressed air system would require modifications as required for starting the proposed diesel engines, although it is believed that the existing compressors are satisfactory.

7.6 Fresh Water System

The only fresh water system changes which could be contemplated are those for replenishing the fresh water engine cooling system.

7.7 Tank Vent System

New Tank vents would be required for all B/F tanks and cells as shown on Figure 7-1. The function of the pressure regulator valves has been discussed previously.

Check valves are located on the top of each cell to permit air to enter the ballast cavity in the event the craft is being defueled in dry dock.

7.8 Electrical System

The steering system must be modified to permit operation both hullborne and foilborne. Whereas hullborne, approximately 180^{o} or more on the wheel should give 35^{o} rudder, only about 10^{o} rudder may be required foilborne. It is possible that the existing gear in the lazarette can be relocated to accommodate this function.

7.9 Hydraulic System

Although it was not reviewed, it is certain that the existing hydraulic system is inadequate to support the new foil incidence and flap actuators. Adequate pump capacity must be obtained through main engine power take-offs and associated reservoirs, filters, etc. located as low in the craft as possible.

The foil and/or flap hydraulic actuator components should be located within the hull to permit servicing as necessary without resorting to dry-docking and access holes in the strut.

7.10 Electrical System

The basic electrical system should require no modification. However, digital autopilot system for control of the foil system must be provided and this may require the inclusion of a dedicated 400 Hz generator.

SECTION 9

HULL MODIFICATIONS

9.0 In order to obtain a better understanding of the physical problems to be encountered in a conversion of the 95 ft. WPB to a Design M174, a ship-check was made on board the WPB "Cape Horn" in drydock at Muller's Boat Yard, Mill Basin, Brooklyn, NY on 1 May 1984.

The major modification to the hull structure would be the removal of the skeg and keel in way of the new strut, and the installation of heavier garboard strakes and an engine room trunk as shown in Figure 9-1.

In order to accommodate the conversion gear boxes against the bulkhead at station 60, it would be necessary to make several major relocations, the exact positions of which could not be determined without a more rigorous evaluation. On the portside, the lube oil separator presents a problem as does the transformer bank on the starboard side. On the centerline, there would be an apparent interference with the aft crew quarter ladder which would require a modification to the main deck hatch.

9.1 In addition, the ship service generators would have to be removed and reinstalled on top of the new strut trunk.

Until a detailed arrangement is made of the engine room it is not possible to determine the exact extent of the relocations required of the equipment on the shell outboard of the diesel engines, but they could be extensive.

Removal of the existing diesel engines and the installation of the new higher horsepower units would require the fabrication of the new engine foundations. To provide additional rigidity to the hull and a decreased beam span for the web frames, these foundations would extend to the shell plating. Figure 9-1, the WPB Midship Section, is included to emphasize the minimal scantlings existing on the craft to which the new structure must be attached.

Table 8-9

USCG HYBRID CONCEPT - CAPACITIES

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO. M174	SUBJECT USCG HYBRID CONCEPT - CAPACITIES		WBS
ANALYST EEH	CHECKER	ANALYSIS DATE 5/10/84	PAGE NO. 3

TABLE 8-9

DYNAMIC LIFT FOR VARIOUS CONDITIONS

CONDITION	KG	DISPL	BUOYANCY	DYNAMIC LIFT
A-HYBRID LIGHT SHIP	12.66	128.83	83.10	45.73
B-FULL LOAD IN HULL	12.78	150.31		67.21
C-FULL LOAD-FUEL	11.04	181.06		97.96
D-FULL LOAD-BALLAST	11.00	181.33		98.23
E-MIN OPER IN HULL	12.75	140.73		57.63
F-MIN OPER-FUEL IN 3+4	12.29	147.41		64.31
G MIN OPER-FUEL IN 3+4 + FULL BALLAST	11.04	168.47		85.37

WET TANK BUOYANCY

	FUEL	BALLAST
GROSS BUOYANCY	83.10 LT	83.10 LT
WEIGHT (BELOW F.B. W.L)	-38.62	-38.62
POSITIVE BUOYANCY	+44.48 LT	+44.48 LT
FULL LIQUID	-35.21	-31.02
NET BUOYANCY	+9.27 LT	+13.46 LT

Table 8-8

USCG HYBRID CONCEPT - CAPACITIES

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT	WBS
M174	USCG HYBRID CONCEPT - CAPACITIES	

ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
EEH		5/9/84	2

TABLE 8-8

MINIMUM OPERATING CONDITION DEVELOPMENT

	WEIGHT	KG	MOM	LCG	MOM
HYBRID LIGHT SHIP	128.83	12.66	1631.16	48.63	6265.53
MIN. OPER COND LOADS					
CREW & EFFECTS	3.00	17.00	51.00	48.00	144.00
PROVISIONS	.83	14.00	11.62	54.00	44.82
FRESH WATER	1.50	11.00	16.50	63.00	94.50
AMMUNITION	.33	15.00	4.95	5.00	1.65
DIESEL OIL IN SHIP TANKS	6.00	12.50	75.00	46.57	279.42
LUBE OIL	0.17	22.45	3.82	46.03	7.83
SEWAGE TANKS	0.07	2.10	0.31	35.00	2.45
MIN OPER LOADS IN HULL	11.90	13.71	163.20	48.29	574.67
• MIN OPER (LESS LOADS IN B/F TANK) (COND E)	140.73	12.75	1794.36	48.61	6840.20
ADD RESERVE FUEL TO B/F TK	6.68	2.50	16.70	26.00	173.68
• MIN OPER WITH B/F FUEL TANKS 3 & 4 (COND F)	147.41	12.29	1811.06	47.58	7013.88
ADD BALLAST TKS 1,2,5,6 & 7	21.06	2.36	49.67	33.35	702.43
• FULL MIN OPER COND (COND G)	168.47	11.04	1860.73	45.80	7716.31

Table 8-7

USCG HYBRID ANALYSIS - CAPACITIES

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID ANALYSIS - CAPACITIES		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
ECH		5/9/84	1

TABLE 8-7

NEW LIGHT SHIP DEVELOPMENT

FROM CAPE UPRIGHT INCLINING 11/10/77

	WEIGHT	KG	MOM	LCG	MOM
INCLINED LIGHT SHIP	85.98	16.96	1458.22	49.02	4214.74
CONV. WEIGHTS TO SUBTRACT	−22.14	13.50	−298.83	50.15	−1110.32
CONV. WEIGHTS TO ADD	64.99	7.26	471.83	48.64	3161.11
• HYBRID LIGHT SHIP (COND A)	128.83	12.66	1631.16	48.63	6265.53

FULL LOAD DEVELOPMENT
(5 DAY MISSION)

	WEIGHT	KG	MOM	LCG	MOM
CREW & EFFECTS	3.00	17.00	51.00	48.00	144.00
PROVISIONS	2.50	14.00	35.00	54.00	135.00
FRESH WATER	4.50	12.00	54.00	63.00	283.50
AMMUNITION ?	1.00	16.50	16.50	5.00	5.00
D.O. IN SHIP'S TANKS	9.77	12.50	122.13	46.57	454.99
LUBE OIL	0.50	22.50	11.25	46.03	23.02
SEWAGE TANKS	0.21	2.20	0.46	35.00	7.35
FULL LOAD LOADS IN HULL	21.48	13.52	290.34	49.02	1052.86
• FULL LOAD (LESS LOADS IN B/F TANK) (COND B)	150.31	12.78	1921.50	48.69	7318.39
ADD FULL FUEL (NO BALLAST IN NO5)	30.75	2.50	76.88	42.35	1302.26
• FULL LOAD WITH B/F TANK (FUEL) (COND C)	181.06	11.04	1998.38	47.61	8620.65
• FULL LOAD WITH B/F TANK (BALLAST)	31.02	2.40	74.57	30.99	961.39
(COND D)	181.33	11.00	1996.07	45.66	8279.78

Table 8-6

USCG HYBRID CONCEPT - TRIM AT FULL LOAD

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT-TRIM AT FULL LOAD		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
EEH		5/29/84	1

TABLE 8-6

FULL FUEL CONDITION

DISPLACEMENT: 181.06 LT LCG = 2.61' AFT ⊗

MOMENT TO CHANGE TRIM 1" = 16.5 FT TON

CB OF CRAFT ON EVEN KEEL = 2.26' AFT ⊗

TRIMMING LEVER 2.61 - 2.26 = 0.35'

$$\text{TRIM - AFT} = \frac{181.06 \times 0.35}{16.5} = 3.84 \text{ INCHES}$$

LONG'L CENTER OF FLOTATION (LCF) = 8.10' AFT ⊗

$$\text{DRAFT FWD} \quad 14.15' - \left(\frac{3.84}{12} \times \frac{53.1}{90}\right) = 13.96'$$

$$\text{DRAFT AFT} \quad 14.15' + \left(\frac{3.84}{12} \times \frac{36.9}{90}\right) = 14.28'$$

FULL BALLAST CONDITION

DISPLACEMENT: 181.33 LT. LCG = -0.66' AFT ⊗

MOMENT TO CHANGE TRIM 1" = 16.5 FT TONS

CB OF CRAFT ON EVEN KEEL = 2.26' AFT OF ⊗

TRIMMING LEVER = 2.26 - 0.66 = 1.60'

$$\text{TRIM - FWD} = \frac{181.33 \times 1.60}{16.5} = 17.58 \text{ INCHES.}$$

LONG'L CENTER OF FLOTATION (LCF) = 8.10' AFT ⊗

$$\text{DRAFT FWD} \quad 14.15' + \left(\frac{17.58}{12} \times \frac{53.1}{90}\right) = 15.01'$$

$$\text{DRAFT AFT} \quad 14.15' - \left(\frac{17.58}{12} \times \frac{36.9}{90}\right) = 13.55'$$

As a 14'-0" draft was specified as the limit for certain ports, several iterations were required to obtain the maximum strut length permissable.

Verification was made thru the final run of the SHCP program which indicated a draft of 14'0" at a displacement of 177.9 tons. As the addition of the ballast raised the full load displacement to 181.33 tons the the tons per inch immersion of 3.02 results is a final even heel draft of about 14'1". A trim check was made to ascertain the actual maximum draft under various loading conditions and is presented on Table 8-6.

Although in the fully ballased condition the bow draft is about 15'-0" with a trim by the bow of 17.58", it would not be necessary to assume this condition except in extreme wind conditions, and then probably only in the open sea. So for docking where the 14'-0" draft is critical the forward ballast tanks would be emptied.

The conversion light ship and full load displacement KG's and LCG's were determined as shown on Table 8-7, and those for a minimum operating condition on Table 8-8.

For the full load development, the loads were those furnished by DTNSRDC for a new craft rather than those for the "Cape Upright". The armament/ammunition weight is, however, arbitrary.

From the foregoing weight determination for the various loading conditions the corresponding dynamic lifts were tabulated on Table 8-9.

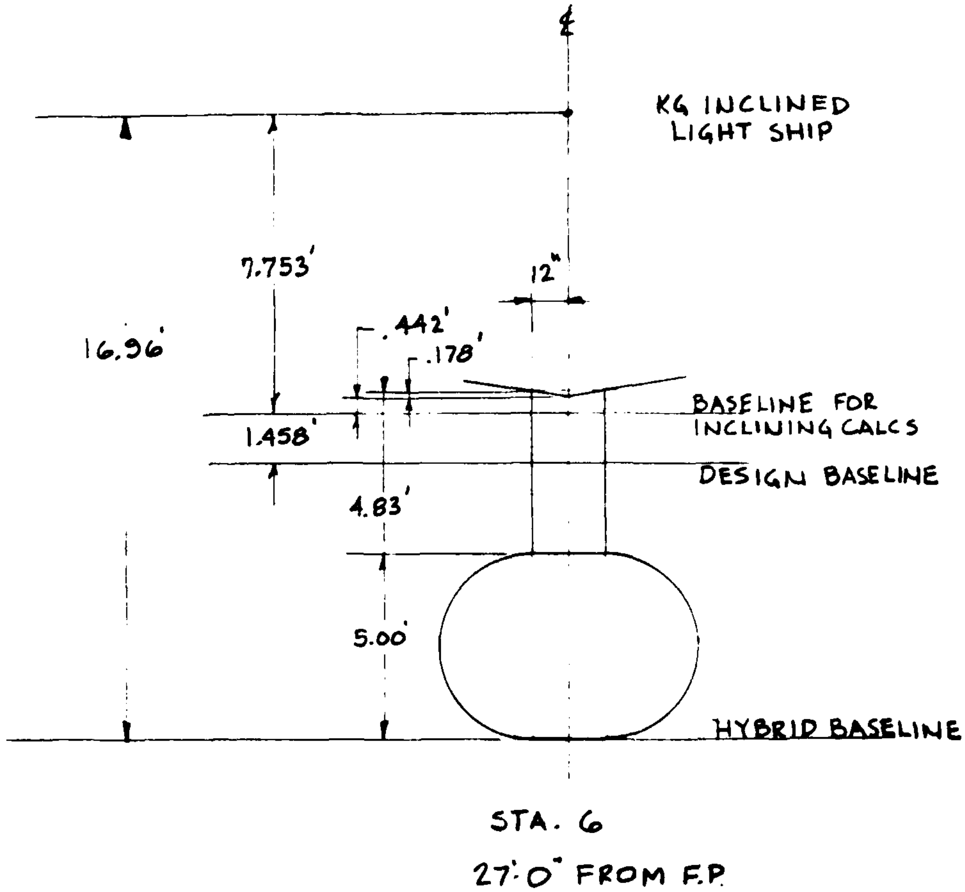


Figure 8-1. KG DERIVATION INCLINED LIGHT SHIP

Table 8-5

U.S. COAST GUARD WPB HYBRID WEIGHT BREAKDOWN

	WPB Cape Upright Ltons	Weight Removed Ltons	Weight Added Ltons	Total Weight Ltons
Group 100 - Hull	36.00	1.25	30.09	64.84
Group 200 - Propulsion	21.00	20.73	20.00	20.27
Group 300 - Electric	5.50	-	.14	5.64
Group 400 - C&S	2.00	-	-	2.00
Group 500 - Auxiliary	8.00	-	.80	8.80
Group 567 - Foils & Controls	-	-	7.40	7.40
Group 600 - Outfit & Furn.	10.78	.16	.66	11.28
Group 700 - Armament	2.50	-	-	2.50
Margin	.20	-	5.90	6.10
. ight Ship	85.98	22.14	64.99	128.83
Full Loads				
Crew & Effects	3.00	-	-	3.00
Provisions	1.50	-	1.00	2.50
Fuel	9.77	-	28.34	38.11
Lube Oil	.50	-	-	.50
Fresh Water	2.78	-	1.72	4.50
Misc.	-	-	3.89	3.89
TOTALS	103.53	22.14	99.94	181.33

Table 8-4

LIQUID IN B/F TANK-FULL BALLAST CONDITION

ESTIMATE OF WEIGHT FOR SHIPS, WORK SHEET
NAVSHIPS 461 8A-2 (REV. 8-65)

U.S.C.G. HYBRID CONCEPT   GROUP NO. ______   PAGE 5   DATE 5/9/84

DESCRIPTION	WEIGHT (~~Pounds~~) (Tons)	CENTER OF GRAVITY: ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. 0: FWD	MOMENTS	AFT	MOMENTS	REFERRED TO: PORT	MOMENTS	STB'D	MOMENTS
BUOYANCY FUEL TANKS											
FULL BALLAST CONDITION											
TANK NO 1	4.52										
		2.50	23.65			14.50	137.17				
2	4.94										
3	4.98										
		2.50	24.90			26.00	258.96				
4	4.98										
5	1.46	.75	1.10			37.50	54.75				
6	4.98										
		2.50	24.90			50.00	498.00				
7	4.98										
8	0.18	0.10	0.02			69.50	12.51				
TOTALS, POUNDS											
TONS	31.02	2.40	74.57			30.99	961.39				

COMPUTING BY   COMPUTING CHECKED

Table 8-3

LIQUID IN B/F TANK-FULL FUEL CONDITION

ESTIMATE OF WEIGHT FOR SHIPS, WORK SHEET
NAVSHIPS 9618A-2 (REV. 6-65)

U.S. CG HYBRID CONCEPT GROUP NO. ______ PAGE 4 DATE 5/9/84

DESCRIPTION	WEIGHT ~~(Pounds)~~ (Tons)	ABOVE BASE	MOMENTS	CENTER OF GRAVITY — REFERRED TO FRAME NO. 0 — FWD	MOMENTS	AFT	MOMENTS	REFERRED TO — PORT	MOMENTS	STB'D	MOMENTS
BUOYANCY/FUEL TANKS											
FULL FUEL CONDITION											
TANK NO 1	3.03	2.50	15.85			14.50	91.93				
2	3.31										
3	3.34	2.50	16.70			26.00	173.68				
4	3.39										
5	1.46	.75	1.10			37.50	54.75				
6	3.34	2.50	16.70			50.00	334.00				
7	3.34										
8	8.64	2.50	21.60			69.50	600.48				
WITH NO BALLAST IN TKS 5	28.34	2.50	70.85			42.35	1200.09				
TOTALS, POUNDS											
TONS	29.80	2.41	71.95			42.11	1254.84				

COMPUTING BY ______ COMPUTING CHECKED ______

Table 8-2

WEIGHTS TO BE REMOVED

ESTIMATE OF WEIGHT FOR SHIPS, WORK SHEET
NAVSHIPS 9610A-2 (REV. 8-65)

U.S.C.G. HYBRID CONCEPT

GROUP NO. ______

DATE 5/9/84

PAGE 3

DESCRIPTION	WEIGHT (Pounds) ~~(Tons)~~	CENTER OF GRAVITY: ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. 0: FWD	MOMENTS	AFT	MOMENTS	REFERRED TO: PORT	MOMENTS	ST'BD	MOMENTS
WEIGHTS TO BE REMOVED											
DDA16V149TI DIESELS (2)	32,794	14.25	467,315			46.0	1,508,524				
REDUCTION GEAR BOXES	9296	13.25	123,172			54.5	506,632				
SHAFTS & PROPELLERS	4290	12.0	51480			68.0	291,720				
RUDDER	112	11.25	1260			88.0	9856				
SKEG	1163	10.0	11630			66.0	76758				
MAIN ENG FDN'S	1512	5.75	8694			49.5	74,844				
ENG. CONTROLS	85	19.0	1615			39.0	3315				
MISC.	350	13.0	4550			46.0	16100				
TOTALS, POUNDS	49602	13.50	669716			50.15	2,487,749				
TONS	22.14										

COMPUTING BY

COMPUTING CHECKED

Table 8-1

WEIGHTS ADDED (Continued)

ESTIMATE OF WEIGHT FOR SHIPS, WORK SHEET
NAVSHIPS 9410A-2 (REV. 6-65)

U.S.CG HYBRID CONCEPT — GROUP NO. — PAGE 2 — DATE 5/8/84

DESCRIPTION	WEIGHT (Pounds)	ABOVE BASE	MOMENTS	FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
		CENTER OF GRAVITY		REFERRED TO FRAME NO. 0				REFERRED TO			
WEIGHTS ADDED (CON'T)											
AUTOPILOT	80	17.0	1360			37.0	2960				
PIPING IN B/E TANK	346	2.6	900			32.0	11,072				
PIPING IN STRUT	879	10.0	8790			39.0	34281				
PIPING IN HULL	612	18.0	11016			49.0	29,988				
MAIN ENGINE FDNS	3284	11.5	37,766			47.0	154,348				
MISC. FDNS	300	9.0	2700			58.0	17,400				
HULL STRUCT. REINF.	2327	11.0	25597			49.5	115,187				
PAINT, WELD, FAB. MISC	1430	6.0	8580			45.0	64,350				
STERN DRIVES & MOTORS	1435	15.0	21,525			92.0	132,020				
ELEC ADDITIONS	300	15.0	4500			65.0	19,500				
ENG. CONTROLS	60	19.0	1140			39.0	2340				
BALLAST	11,200	0	0			45.0	540,000				
	22,253	5.57	123,874			50.48	1123446				
SHEET 1 TOTALS	110,087	7.60	836742			48.27	5,314,147				
	132,340										
MARGIN 10%	13234										
TOTALS, POUNDS	145,574	7.26	960,616			48.64	6,437593				
TONS	64.99										

COMPUTING BY — COMPUTING CHECKED

Table 8-1
WEIGHTS ADDED

ESTIMATE OF WEIGHT FOR SHIPS, WORK SHEET
NAVSHIPS 9610A-2 (REV. 6-65)

U.S.C.G. HYBRID CONCEPT GROUP NO. ____ DATE 5/8/84 PAGE 1

DESCRIPTION	WEIGHT (Pounds)	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. 0: FWD	MOMENTS	AFT	MOMENTS	REFERRED TO: PORT	MOMENTS	STBD	MOMENTS
WEIGHTS ADDED											
BUOYANCY/FUEL TANK	35,986	2.47	88885			41.6	1,497,018				
STRUT/RUDDER	14,339	7.33	105,105			57.44	823,632				
FWD FOIL	12,852	2.5	32,130			37.0	475,524				
AFT FOIL	3130	1.0	3130			77.5	242,575				
PROPELLER	980	2.5	2450			88.75	86,975				
PROPELLER SHAFT	2692	2.5	6730			76.0	204592				
STERN TUBE & BRGS	1160	2.5	2900			74.5	86420				
LOWER BEVEL GEAR BOX	960	2.6	2496			58.5	56160				
VERTICAL SHAFT & BRGS	920	8.5	7820			58.5	53820				
COMBINING BOX	950	14.5	13,775			58.5	55,575				
CLUTCHES & SHAFTS	2100	14.5	30,450			58.5	122,850				
UPPER BEVEL GEAR BOX (2)	1520	14.5	22040			58.5	88920				
ENGINE SHAFTS (2)	638	14.5	9251			54.5	34,771				
PIELSTICK DIESELS (2)	30,870	16.0	493,920			46.5	1,435,455				
EXHAUST SYSTEM (OVER EXIST)	450	26.0	11,700			48.0	21,600				
FOIL INCIDENCE SYS FWD	360	7.0	2520			39.0	14,040				
AFT	180	8.0	1440			79.0	14220				
TOTALS, POUNDS	110087	7.60	836742			48.27	5314147				
TONS											

COMPUTING BY ____ COMPUTING CHECKED ____

SECTION 8
WEIGHT SUMMARY

8.0 The basis for the M174 weights and balance determination was the stability test data derived from the inclining test conducted on WPB95303, the "Cape Upright," on 10 Nov. 1977. This appeared to be the most accurate information available and was well documented.

The conversion weights to be added are tabulated on Table 8-1. Where possible these weights were derived from manufacturers literature and documented weights for such items as gear boxes on the Grumman Israeli hydrofoil (M161). Other weights were based upon scantling calculations and the remainder on estimations.

As over 50% of the weights to be added have a fairly reliable basis, a margin of only 10% has been added to the total conversion weights in lieu of a more conservative 15%. It is to be noted that to insure marginal stability in most high wind conditions the five tons added to the bottom of the B/F tank is carried as ballast rather than including it in the tank weight.

Where possible, weights to be removed, Table 8-2, were derived from excerpts from the Ships Information Book furnished by the USCG. The remainder of the weights were calculated from available information.

Tables 8-3 and 8-4 tabulate the weights and centers for the liquids in the buoyancy/fuel tank in the full fuel and full ballast conditions respectively.

Table 8-5 is a weight breakdown for the WPB hybrid by the standard Ship Work Breakdown Structure (SWBS). Shown are the "Cape Upright" weight, the weights removed, weights added and total weight for the M174 design.

8.1 From the foregoing tables and data the M174 conversion light ship was determined to be 128.83 tons with a corresponding KG of 12.66 ft. All KG's have been referenced to the bottom of the B/F tank and derived for the "as inclined" light ship as shown in Figure 8-1.

The existing bolted plates in the main deck would also require review and possible modification to permit servicing the diesels.

System modification have not been detailed except as previously noted in Section 7.

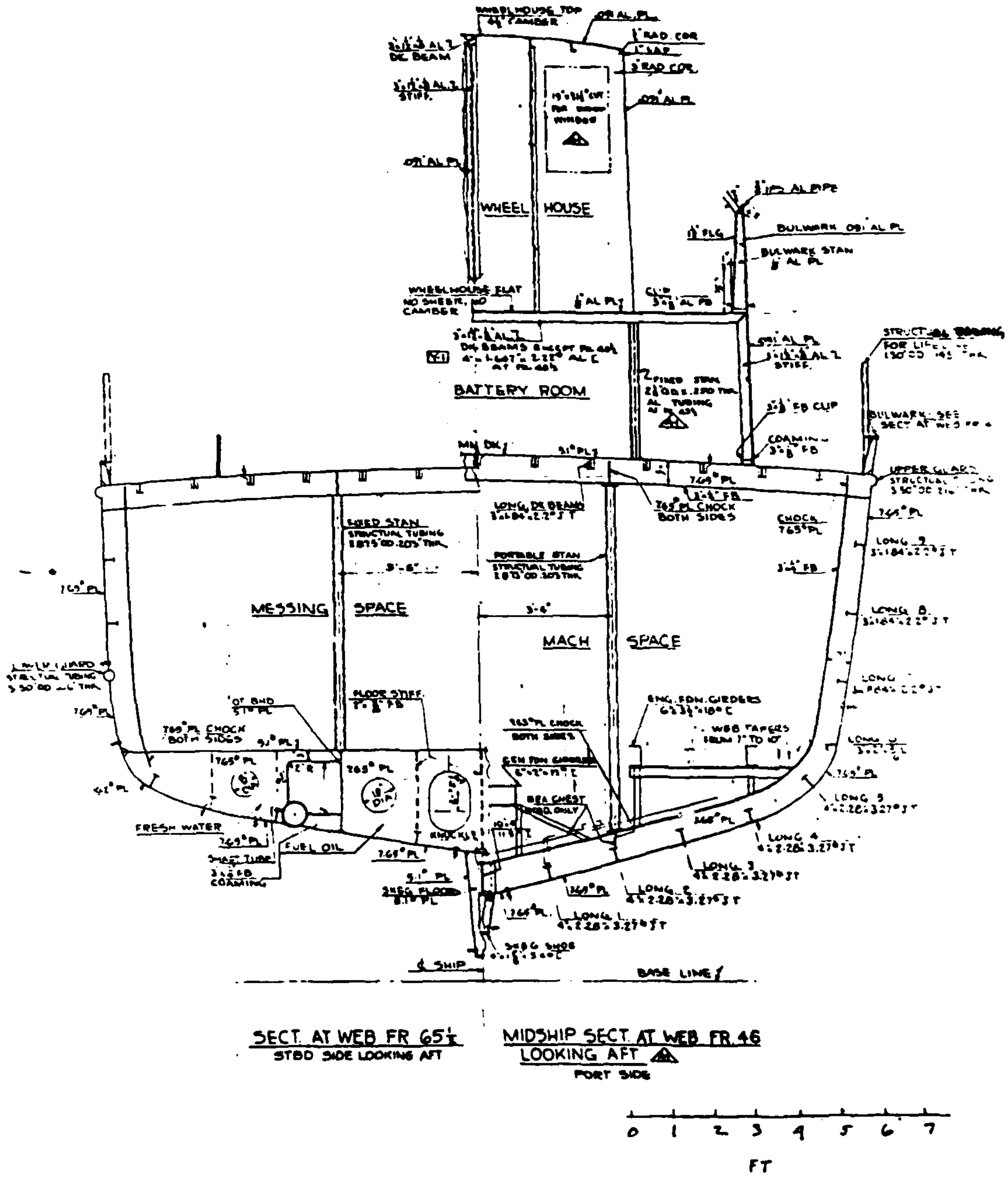


Figure 9-1. MIDSHIP SECTION - EXISTING 95' WPB

SECTION 10
INTACT STABILITY

10.0 General

A check of the intact stability of the hybrid craft was required due to the positive buoyancy of the tank and its effect on the location of the center of gravity when installed. Before discussing the procedure used to determine the stability of the hybrid craft, it is prudent to report here that calculations indicate that the 180-ton hybrid design M174 (including buoyancy/fuel tank as depicted herein) can become neutrally stable in high beam winds if the craft is allowed to operate at relatively low displacements. This stability characteristic is unlike that of a conventional monohull which tends to capsize after reaching a certain heel angle. The M174 design will seek a specific heel angle, when below a certain displacement, and neither return to zero heel nor capsize as long as intact conditions are maintained. The approach used to resolve this problem is discussed in the paragraphs following.

The addition of the fuel tank to a 103.5-ton displacement craft produces two effects which relate to the safety of the ship under high beam wind loadings. The first is independent of the net weight or buoyancy of the tank, and is an increase in heeling moment due to a given wind as a result of lowering the center of lateral resistance of the underwater appendages. The second effect is related to the tank's net weight, with positive buoyancy detracting from the ship's righting moment at any heel angle and negative buoyancy providing an improvement. From the standpoint of reducing the loading on the foil system, and therefore the induced drag, it is desirable to have a positively buoyant B/F tank. However, this is counter to the desire to carry maximum liquid in the tank and to provide adequate resistance to wind heel. This dilemma is partially resolved by determining the limits on tank positive buoyancy for adequate intact stability in a beam wind using the criteria of Sarchin and Goldberg, as outlined in Navy Design Data Sheet 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships." The criterion applied to this design is the "six-tenths" righting arm rule exclusively, and

does not include the area criterion used for conventional ships to account for roll energy. The reason is that the ship with the B/F tank in place will have roll characteristics which do not relate to a conventional hull; i.e., the amount of roll resistance would be relatively high, and the dynamics would have very little relation to a conventional ship. Therefore, the conventional roll energy approach does not appear to be valid. Stability judgments based on righting arms alone should be adequate for the feasibility configuration with the B/F tank.

10.1 M174 Design

The intact stability calculations were conducted in the classic naval architectural manner, with the tank considered integral to the ship and its displacement and center of buoyancy independent of its contents. The tank and strut configuration is shown on Figure 3-1 and 5-1 and has a displacement of 89.38 L.T. Standard righting arm curves were generated with the NAVSEA Ship Hull Characteristics Program (SHCP) computer program for a range of displacements and vertical centers of gravity as determined on Tables 8-6 and 8-7. This, in effect, provided a "map" of stability for conceivable loading conditions. To provide a basis for comparison, the hydrostatic characteristics were computed by the SHCP program, Table 10-1, and a Curves of Form chart plotted, Figure 10-1. The next step was to determine the wind heeling arms for the 40- through 80-knot gradient beam winds. The underwater center of lateral area was determined and thence the heeling moments and heeling arms per DDS 079-1 and as tabulated in Tables 10-2 through 10-4. Wind Heeling Arm Curves for 40 through 80 knots were plotted and are shown on Figures 10-2 through 10-6.

The SHCP program was utilized to generate Intact Cross Curve Values at 0 ft. KG, Table 10-5, and plotted on Figure 10-7. From these curves and those of Figures 10-2 through 10-6, the heeling and righting arms for any combination of displacement and KG may be determined.

Table 10-1

HYDROSTATICS

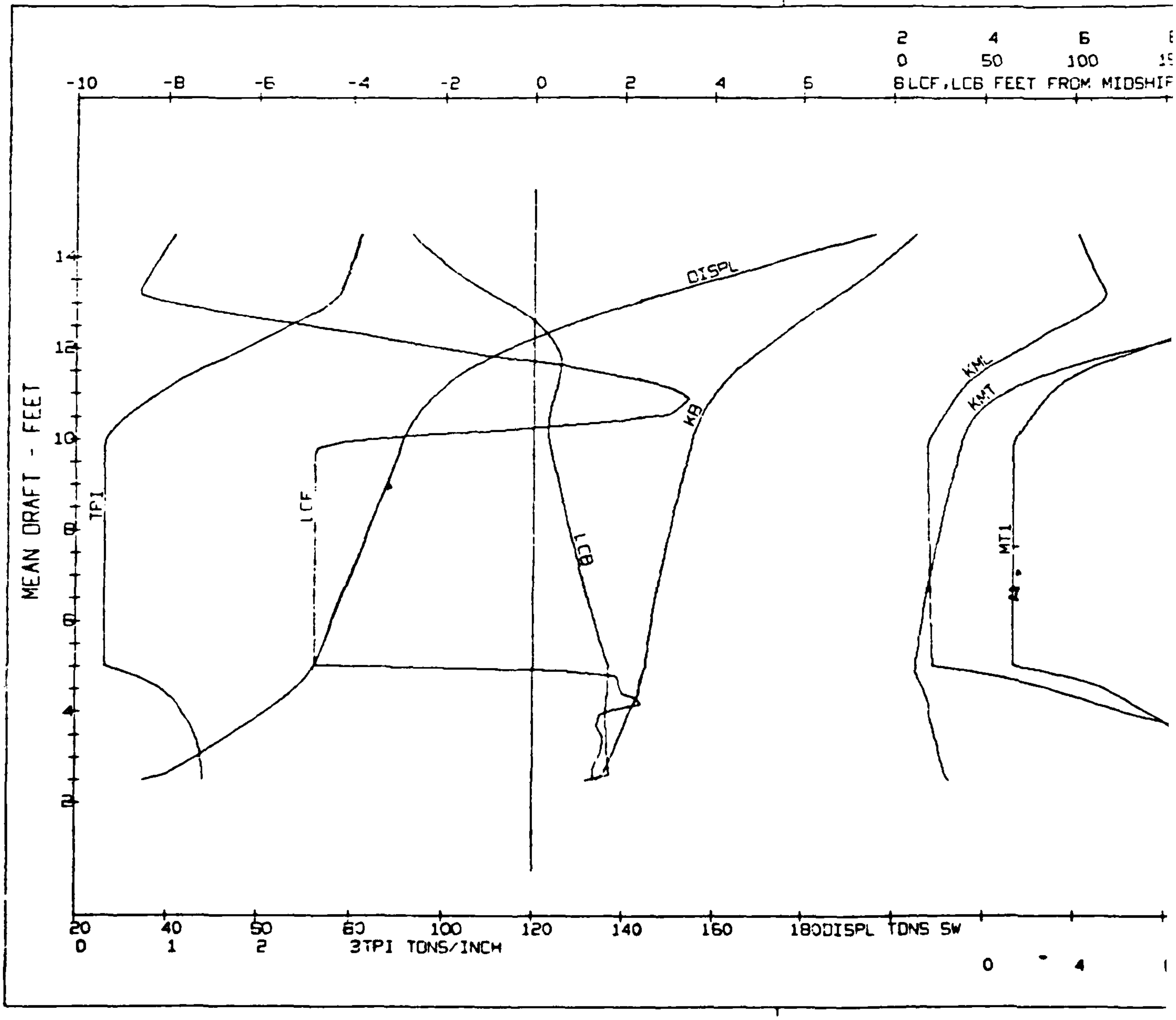
SHIP USCG HYBRID CONCEPT SI AL NUMBER- 1 DATE- 4/3/84

HYDROSTATICS - PART 1 TRIM 0.0 FEET WITH APPENDAGES

	DRAFT	VOLUME	DISPLACEMENT	LCB	KB	WETTED SURFACE	PRISMATIC COEF	WPLANE COEF	WPLANE I COEF
	2.50	1326.	37.9	1.72	1.50	834.	1.003	0.936	0.885
	5.00	2535.	72.4	1.66	2.50	1528.	0.955	0.852	0.862
	6.00	2668.	76.2	1.34	2.65	1701.	0.941	0.740	0.679
	7.00	2801.	80.0	1.05	2.83	1854.	0.929	0.740	0.679
	7.75	2901.	82.9	0.85	2.99	1969.	0.921	0.740	0.679
	9.00	3068.	87.7	0.55	3.28	2160.	0.909	0.740	0.679
	9.75	3168.	90.5	0.38	3.47	2275.	0.903	0.740	0.679
	13.00	4997.	142.8	-0.63	6.57	3580.	0.767	0.795	0.711
	13.25	5295.	151.3	-1.07	6.94	3655.	0.769	0.817	0.757
	13.50	5601.	160.0	-1.48	7.29	3703.	0.772	0.819	0.757
	13.75	5912.	168.9	-1.84	7.62	3751.	0.774	0.822	0.758
DWL	14.00	6227.	177.9	-2.16	7.94	3799.	0.776	0.824	0.758
	14.25	6545.	187.0	-2.45	8.24	3847.	0.779	0.826	0.758
	14.50	6868.	196.2	-2.71	8.53	3894.	0.781	0.828	0.757

HYDROSTATICS - PART II TRIM 0.0 FEET WITH APPENDAGES

	DRAFT	WPLANE AREA	LCF	TPI	CIDOFTS	LONG. BM	TRNSV BM	LONG. KM	TRNSV KM	MT1
	2.50	589.	1.33	1.40	-0.25	265.9	1.72	267.4	3.22	9.3
	5.00	153.	-0.19	0.37	0.01	29.7	0.02	32.2	2.52	2.0
	6.00	133.	-4.74	0.32	0.20	19.0	0.02	21.6	2.66	1.3
	7.00	133.	-4.74	0.32	0.20	18.1	0.01	20.9	2.85	1.3
	7.75	133.	-4.74	0.32	0.20	17.5	0.01	20.5	3.00	1.3
	9.00	133.	-4.74	0.32	0.20	16.5	0.01	19.8	3.29	1.3
	9.75	133.	-4.74	0.32	0.20	16.0	0.01	19.5	3.49	1.3
	13.00	1168.	-7.99	2.78	2.96	107.4	4.64	114.0	11.21	14.2
	13.25	1215.	-8.64	2.89	3.33	109.9	4.83	116.8	11.77	15.4
	13.50	1233.	-8.48	2.94	3.32	106.1	4.74	113.4	12.03	15.7
	13.75	1250.	-8.32	2.98	3.30	102.6	4.64	110.2	12.27	16.0
DWL	14.00	1267.	-8.16	3.02	3.28	99.3	4.55	107.3	12.49	16.4
	14.25	1283.	-8.00	3.06	3.26	96.3	4.47	104.5	12.71	16.7
	14.50	1299.	-7.84	3.09	3.23	93.4	4.38	102.0	12.91	17.0



2 4 6
0 50 100
-10 -8 -6 -4 -2 0 2 4 6 8LCF,LCB FEET FROM MIDSHIP
MEAN DRAFT - FEET
DISPL
KB
LCB
LCF
TPI
KML
KMT
MT1
20 40 60 80 100 120 140 160 180DISPL TONS SW
0 1 2 3TPI TONS/INCH
0 4

2

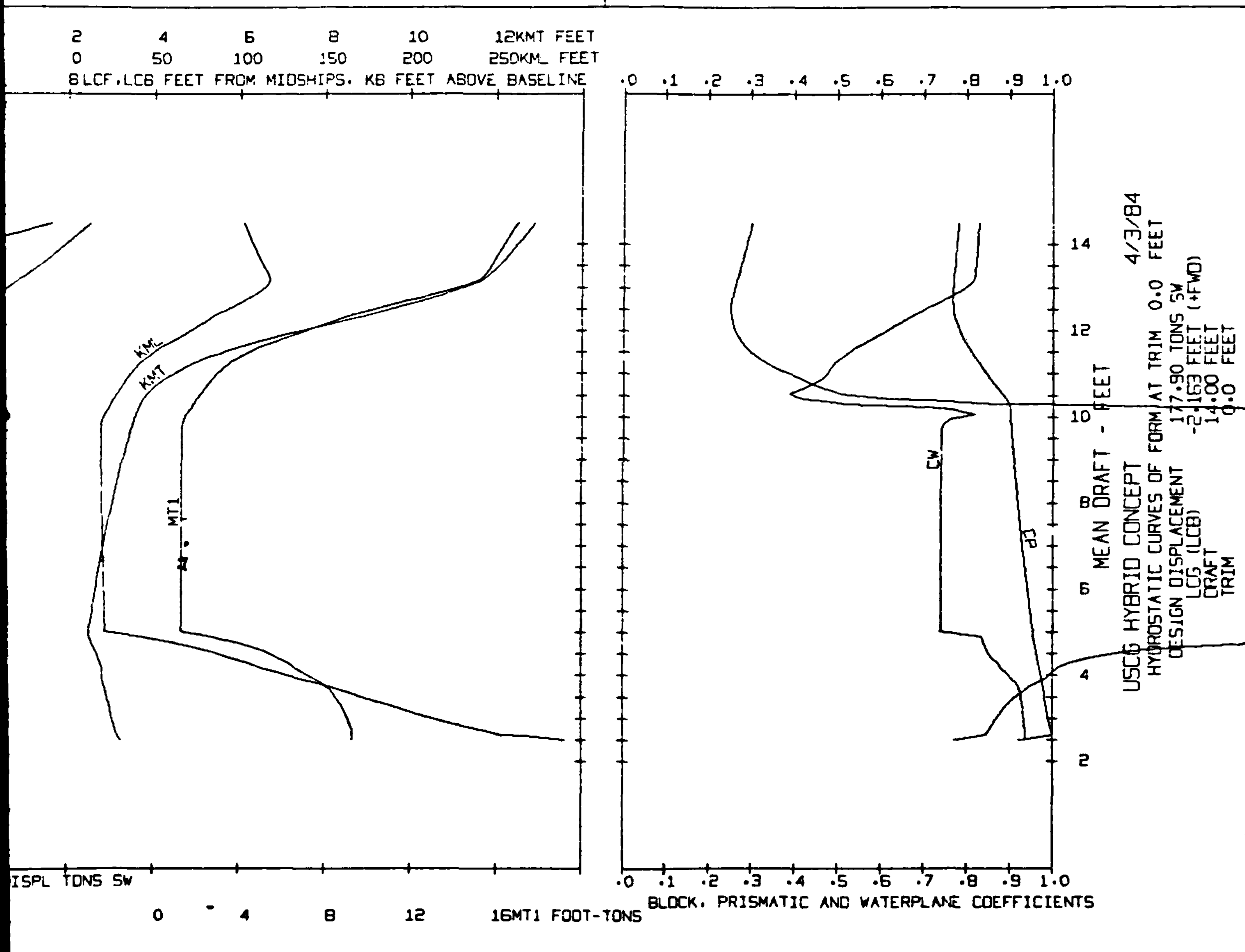
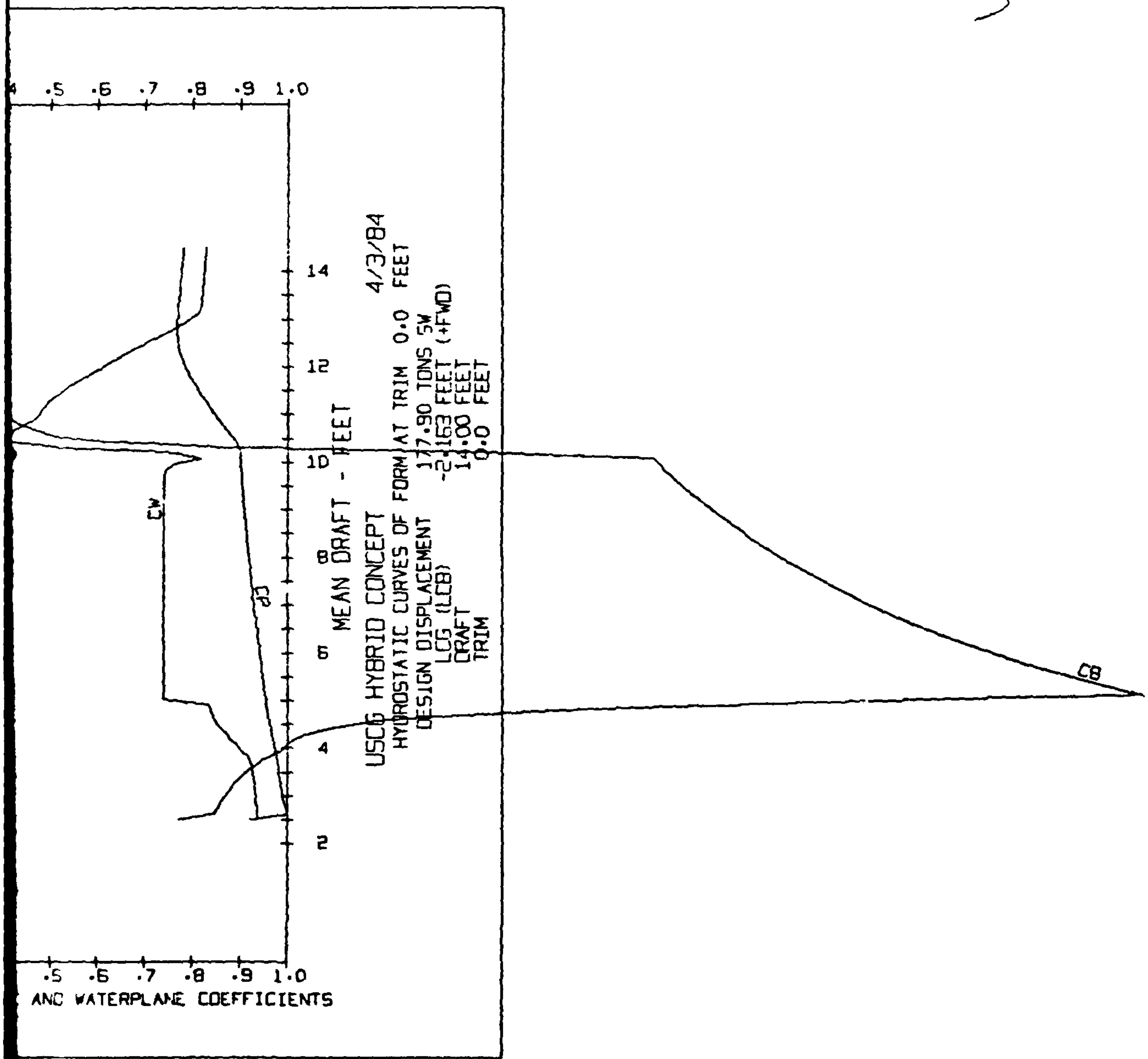


Figure 10-1. CURVES OF FORM

3



S OF FORM

FIGURE 10-1

Table 10-2

HEELING MOMENTS - 100-KT WIND/SAIL AREAS

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - INTACT STABILITY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
			1

HEELING MOMENTS - 100K GRADIENT WIND

DDS-079 - CENTER OF LATERAL RESISTANCE BELOW W.L.

	A	FT	M
HULL	338	1.92	648
STRUT	310	6.50	2015
TANK	414	11.50	4761
	1062	6.99'	7424

MOMENT OF PROJECTED SAIL AREA (2 FT LAYERS)

LAYER	AREA ft^2	MULT (DDS-079)	MOMENT
1	181	.04	7.24
2	183	.09	16.47
3	185	.13	24.05
4	168	.17	28.56
5	90	.20	18.00
6	60	.24	14.40
7	59	.28	16.52
8	38	.31	11.78
9	34	.35	11.90
10	11	.40	4.40
11	2	.44	.88
12	2	.48	.96
13	1	.52	.52
14	1	.57	.57
15	3	.61	1.83
16	1	.66	.66
	1019 ft^2		158.74 ft Tons

Table 10-3

HEELING MOMENTS - ALTERNATE WIND VELOCITIES

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT- INTACT STABILITY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
			2

MOMENTS FOR ALTERNATE WIND VELOCITIES

40 K	$(40/100)^2 \times 158.74 =$	25.40 ft tons
50 K	$(50/100)^2 \times 158.74 =$	39.69
60 K	$(60/100)^2 \times 158.74 =$	57.15
70 K	$(70/100)^2 \times 158.74 =$	77.78
80 K	$(80/100)^2 \times 158.74 =$	101.59

HEELING ANGLE FACTOR $\cos^2\theta$

ANGLE OF HEEL	COS	$\cos^2$
10	0.9848	0.9698
20	0.9397	0.8830
30	0.8660	0.7500
40	0.7660	0.5868
50	0.6428	0.4132
60	0.5000	0.2500
70	0.3420	0.1170
80	0.1736	0.0302
90	0.0000	0.0000
5°	0.9962	0.9924

Table 10-4

HEELING ARMS

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT. INTACT STABILITY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO. 3

HEELING ARMS HA= $M \cos^2\theta/\Delta$

HEEL ANGLE	WIND VELOCITY 40k	50k	60k	70k	80k
10	24.63/Δ	38.49/Δ	55.42/Δ	75.43/Δ	98.52/Δ
20	22.43/Δ	35.05/Δ	50.46/Δ	68.68/Δ	89.70/Δ
30	19.05/Δ	29.77/Δ	42.86/Δ	58.34/Δ	76.19/Δ
40	14.90/Δ	23.29/Δ	33.54/Δ	45.64/Δ	59.61/Δ
50	10.50/Δ	16.40/Δ	23.61/Δ	32.14/Δ	41.98/Δ
60	6.35/Δ	9.92/Δ	14.29/Δ	19.45/Δ	25.40/Δ
70	2.97/Δ	4.64/Δ	6.69/Δ	9.10/Δ	11.89/Δ
80	0.77/Δ	1.20/Δ	1.73/Δ	2.35/Δ	3.07/Δ
5°	25.21/Δ	39.39/Δ	56.72/Δ	77.19/Δ	100.82/Δ

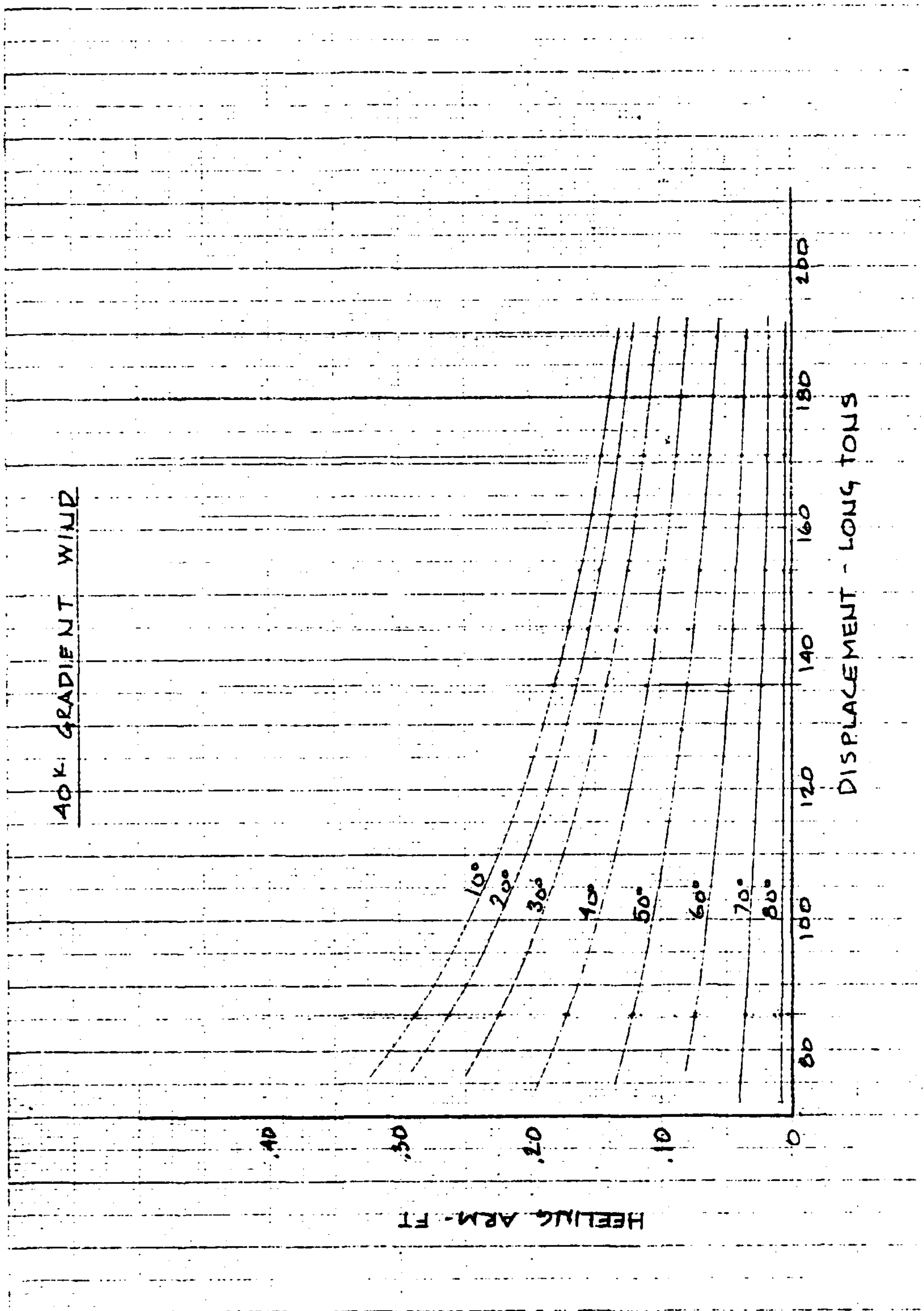


Figure 10-2. HEELING ARM CURVES - 40 K GRADIENT WIND

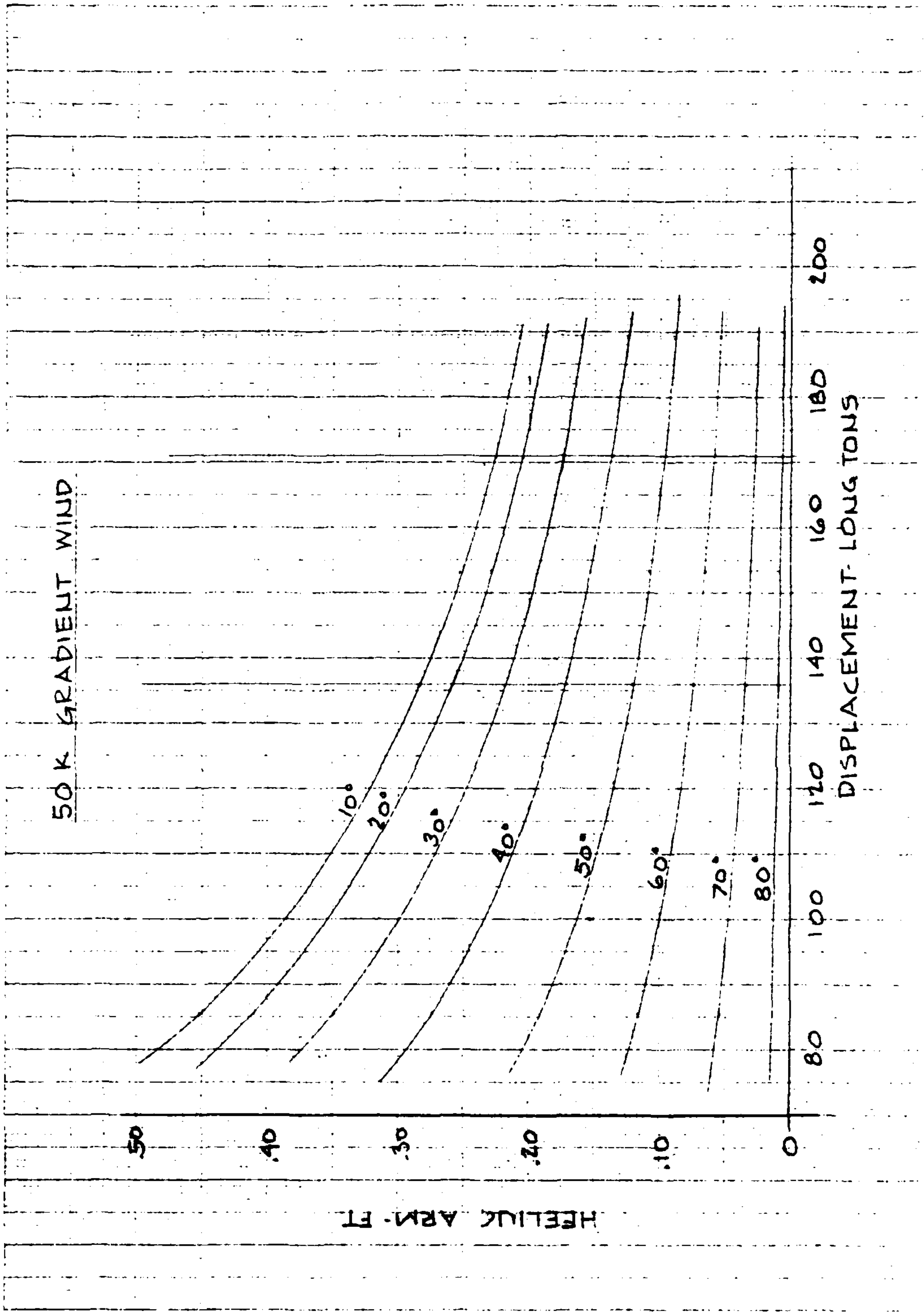


Figure 10-3. HEELING ARM CURVES - 50K GRADIENT WIND

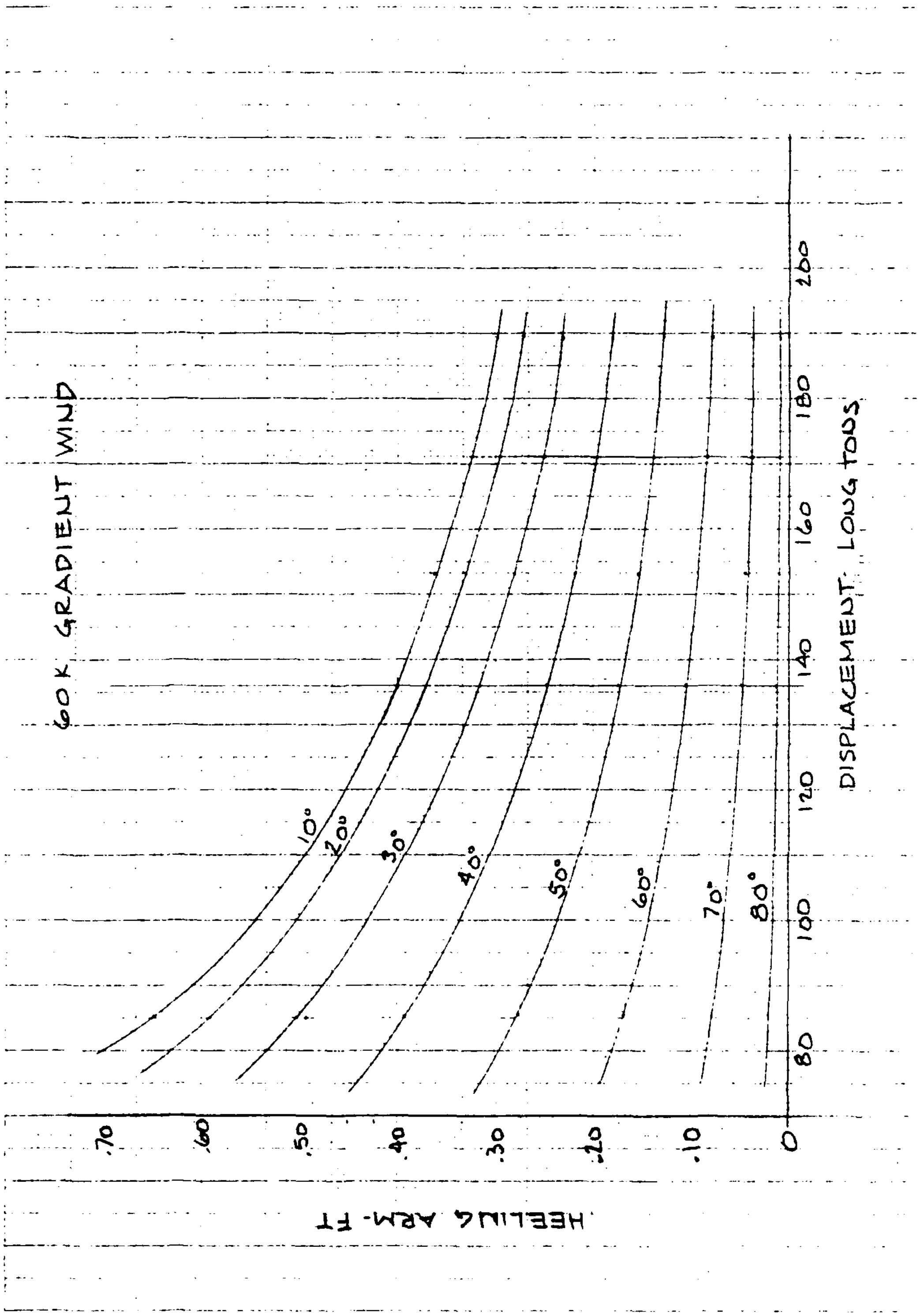


Figure 10-4. HEELING ARM CURVES - 60K GRADIENT WIND

10.2 Variant with Strut Having Reduced Height (Short Strut)

Since the full load intact stability curve of Figure 10-9 only marginally satisfies the six-tenths rule, it was decided to investigate a design with its strut having a reduced height of .5 feet. The offsets were appropriately altered and run on a modified version of the Advanced Surface Ship Evaluation Tool (ASSET). The program was first checked to verify that ASSET gave essentially the same intact stability results as SHCP with the original strut height. Calculated points (o) are shown on Figures 10-8 and 10-9.

The full load KG was re-estimated to be 10.7 ft. (instead of 11.0 ft.) and only a minor change to 180 L. tons was reflected in full load weight due to the shorter strut. The calculated points (x) for the short strut are also shown plotted in Figures 10-8 and 10-9. It can be seen that the righting arm is only somewhat improved in the 20° to 50° heel angle region in Figure 10-9 (Full Load Condition), whereas there is appreciable improvement in righting arm curve, with the shorter strut, for the Minimum Operating Condition in Figure 10-8.

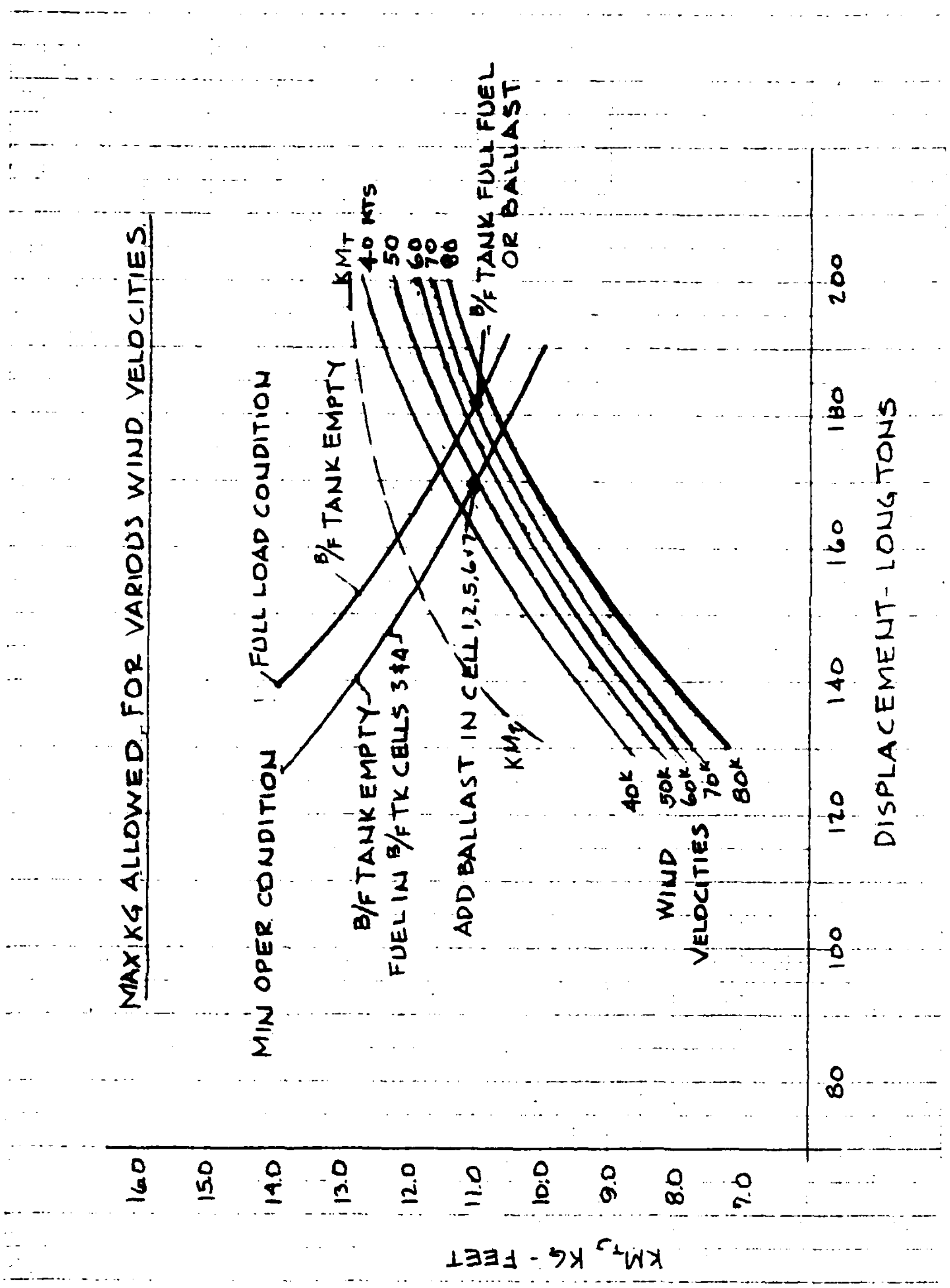


Figure 10-10. MAX KG ALLOWED FOR VARIOUS WIND VELOCITIES

Table 10-7

KG REQUIRED FOR VARIOUS WIND VELOCITIES (Continued)

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - STABILITY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
ECH		5/15/84	2

MAX KG REQ'D (CONT'D)

50 K GRADIENT WIND — INTERCEPT AT 5° MAX RA AT 25°

DISPLACEMENT - L.T.

		130	150	170	190
HA	=	.31	.26	.24	.22
RA_{AH}	=	.62	.43	.40	.37
$RA_{KG=0}$	=	4.00	4.65	5.05	5.40
KG	=	8.23	9.99	11.00	11.90

40 K GRADIENT WIND — INTERCEPT AT 6° MAX RA AT 20°

HA	=	.20	.17	.155	.14
RA_{AH}	=	.33	.28	.26	.23
$RA_{KG=0}$	=	3.30	3.80	4.15	4.42
KG	=	8.68	10.29	11.37	12.25

Table 10-7

KG REQUIRED FOR VARIOUS WIND VELOCITIES

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - STABILITY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
EW		5/15/84	1

MAX KG REQUIRED FOR VARIOUS WIND VELOCITIES

80K GRADIENT WIND — ASSUME: INTERCEPT AT 20°, MAX RA AT 40°

	DISPLACEMENT-L.T 130	150	170	190
HEELING ARM	.71'	.60	.54	.47
RIGHTING ARM (HA/.6)	1.18	1.00	0.90	0.78
RIGHTING ARM @ KG=0	5.82	6.78	7.45	7.97
$KG = (RA_0 - RA_{HW})/\sin 40°$	7.21	8.99	10.19	11.19

70K GRADIENT WIND — INTERCEPT AT 15°, MAX RA AT 40°

	130	150	170	190
HA =	.56	.48	.42	.39
RA_{HW} =	.93	.80	.70	.65
$RA_{KG=0}$ =	5.82	6.78	7.45	7.97
KG =	7.60	9.30	10.50	11.39

60K GRADIENT WIND — INTERCEPT AT 10°, MAX RA AT 30°

	130	150	170	190
HA =	.42	.37	.33	.30
RA_{HW} =	.70	.62	.55	.50
$RA_{KG=0}$ =	4.67	5.36	5.88	6.30
KG =	7.94	9.48	10.66	11.60

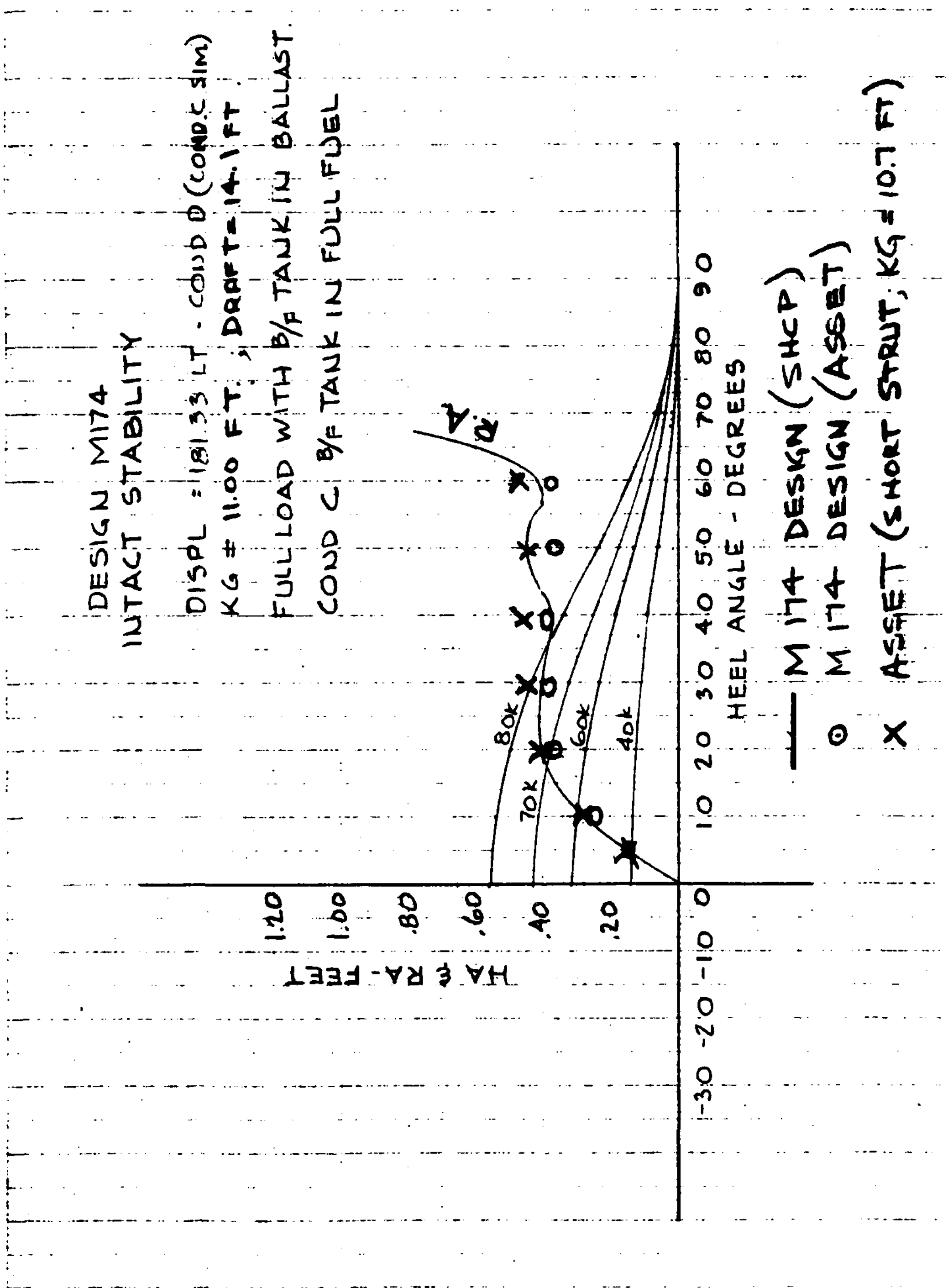


Figure 10-9. INTACT STABILITY 181.33 L.TON KG = 11.00'

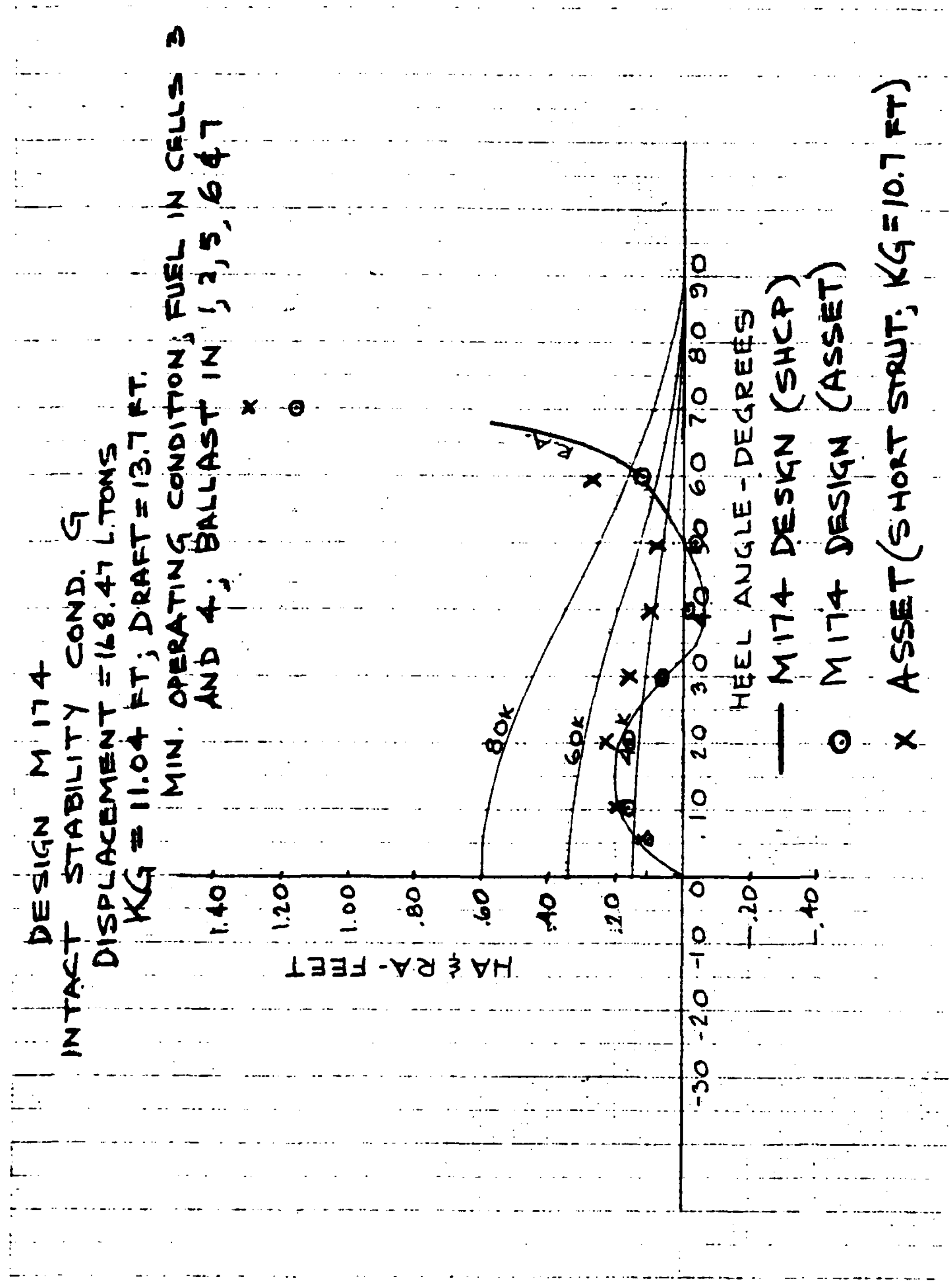


Figure 10-8. INTACT STABILITY 168.47 L.TON KG = 11.04'

Table 10-6

INTACT CURVES OF STATICAL STABILITY (Continued)

SHIP USCG HYBRID CONCEPT SF 'AL NUMBER- 1 DATE- 4/3/84

INTACT CURVES OF STATICAL STABILITY

DISPL	LCG	POLE HT	HEEL	RA	TCB	VCB	DRAFT	TRIM
178.650	-2.188	11.15	10.000	0.229	0.783	8.031	13.973	-0.031
			20.000	0.314	1.409	8.197	13.748	-0.382
			30.000	0.267	1.886	8.418	13.269	-1.012
			40.000	0.188	2.297	8.706	12.457	-1.826
			50.000	0.259	2.756	9.175	11.320	-2.733
			60.000	0.233	3.079	9.642	9.674	-3.383
			70.000	1.082	3.676	10.964	8.009	-3.756
			80.000	2.387	4.178	12.837	4.933	-6.373
			89.000	3.441	4.341	14.516	-50.259	-58.818
181.330	-2.276	11.00	10.000	0.270	0.782	8.122	14.049	-0.020
			20.000	0.404	1.417	8.289	13.832	-0.343
			30.000	0.404	1.902	8.514	13.363	-0.943
			40.000	0.364	2.317	8.805	12.562	-1.728
			50.000	0.449	2.767	9.265	11.448	-2.613
			60.000	0.418	3.073	9.709	9.826	-3.240
			70.000	1.212	3.639	10.965	8.175	-3.559
			80.000	2.496	4.132	12.806	5.263	-6.894
			89.000	3.543	4.294	14.469	-46.402	-52.369

Table 10-6

INTACT CURVES OF STATICAL STABILITY

SHIP USCG HYBRID CONCEPT SI 'AL NUMBER- 1 DATE- 4/3/84

INTACT CURVES OF STATICAL STABILITY

DISPL	LCG	POLE HT	HEEL	RA	TCB	VCB	DRAFT	TRIM
128.830	0.038	12.66	10.000	-0.604	0.572	5.942	12.391	-0.506
			20.000	-1.370	0.951	6.042	11.962	-1.470
			30.000	-2.120	1.276	6.194	11.291	-2.566
			40.000	-2.551	1.774	6.577	10.397	-3.931
			50.000	-2.801	2.277	7.093	8.956	-5.113
			60.000	-1.965	3.248	8.516	7.131	-6.456
			70.000	-0.094	4.385	10.964	4.732	-8.159
			80.000	1.680	5.062	13.473	-2.239	-17.604
			89.000	2.880	5.255	15.448	-132.023	-188.781
140.730	-0.523	12.75	10.000	-0.411	0.679	6.530	12.819	-0.403
			20.000	-1.029	1.126	6.648	12.445	-1.222
			30.000	-1.682	1.484	6.815	11.817	-2.245
			40.000	-2.054	1.978	7.198	10.952	-3.516
			50.000	-2.303	2.453	7.685	9.538	-4.583
			60.000	-1.834	3.201	8.785	7.717	-6.113
			70.000	-0.229	4.213	10.973	5.564	-7.132
			80.000	1.397	4.844	13.314	-0.369	-15.018
			89.000	2.554	5.028	15.216	-111.421	-156.961
147.410	-0.868	12.29	10.000	-0.238	0.721	6.832	13.039	-0.312
			20.000	-0.691	1.205	6.959	12.695	-1.040
			30.000	-1.207	1.582	7.135	12.092	-2.010
			40.000	-1.651	1.952	7.395	11.172	-3.076
			50.000	-1.665	2.536	7.989	9.857	-4.213
			60.000	-1.324	3.175	8.929	8.046	-4.843
			70.000	0.171	4.118	10.973	6.016	-6.477
			80.000	1.743	4.725	13.227	0.644	-13.395
			89.000	2.864	4.907	15.069	-100.432	-140.713
158.318	-1.017	12.78	10.000	-0.287	0.735	6.957	13.131	-0.270
			20.000	-0.787	1.235	7.088	12.800	-0.960
			30.000	-1.352	1.621	7.268	12.208	-1.902
			40.000	-1.847	1.993	7.530	11.297	-2.947
			50.000	-1.923	2.568	8.115	9.994	-4.050
			60.000	-1.700	3.163	8.991	8.189	-4.717
			70.000	-0.304	4.077	10.972	6.209	-6.187
			80.000	1.215	4.674	13.190	1.075	-12.669
			89.000	2.319	4.854	15.014	-95.517	-132.477
168.470	-1.823	11.04	10.000	0.184	0.781	7.673	13.681	-0.086
			20.000	0.186	1.368	7.827	13.421	-0.550
			30.000	0.067	1.813	8.034	12.902	-1.300
			40.000	-0.064	2.207	8.311	12.052	-2.208
			50.000	0.034	2.704	8.815	10.839	-3.205
			60.000	0.130	3.104	9.398	9.120	-3.891
			70.000	1.234	3.818	10.964	7.374	-4.547
			80.000	2.649	4.354	12.962	3.630	-8.380
			89.000	3.733	4.524	14.694	-65.676	-83.859

The heeling arms determined by the above procedure were then plotted against the righting arms, Table 10-6, for the corresponding displacements producing Figures 10-8 and 10-9 (the classic curves of DDS 079-1) for two extreme loading conditions.

The extreme loading conditions for the ship, including the tank, were assumed to be the Full Load Condition and the Minimum Operating Condition, representing realistic departure and arrival conditions of the ship. The weights and centers for the conditions were taken from Tables 8-6 and 8-7. At displacements of 153 tons and 140 tons, respectively, (see Figure 10-10) the buoyancy/fuel tank is empty and liquid is considered added to the buoyancy/fuel tank until the ship's KG is lowered to its minimum value to determine its relationship to the wind criteria curves (40 through 80 knots) for the corresponding displacement. This is illustrated by superimposing the requirements curves, developed as shown in Table 10-7, on the load conditions at various tank weights, Figure 10-10. The results indicated that inadequate volume exists in the tank as defined to contain sufficient liquid to lower the center of gravity (KG) for the required stability in an 80-knot beam wind without the addition of about 4 tons of fixed ballast. However, from this figure it is seen that intact stability criteria is satisfied for the full load and minimum operating conditions (fully ballasted) at 70- and 50-knot beam winds, respectively. These wind conditions may be acceptable for a demonstrator vehicle.

Obviously there are two basic approaches to alleviating this condition and increasing the allowable beam wind condition: either lower the center of gravity or raise the center of buoyancy. Inasmuch as the net change must be accomplished within the tank, the two become interrelated as any attempt to modify one condition has an effect of some magnitude on the other. For example, to reduce the buoyancy of the tank requires a reduction in tank volume which would therefore reduce the amount of structural material required, consequently raising the center of gravity.

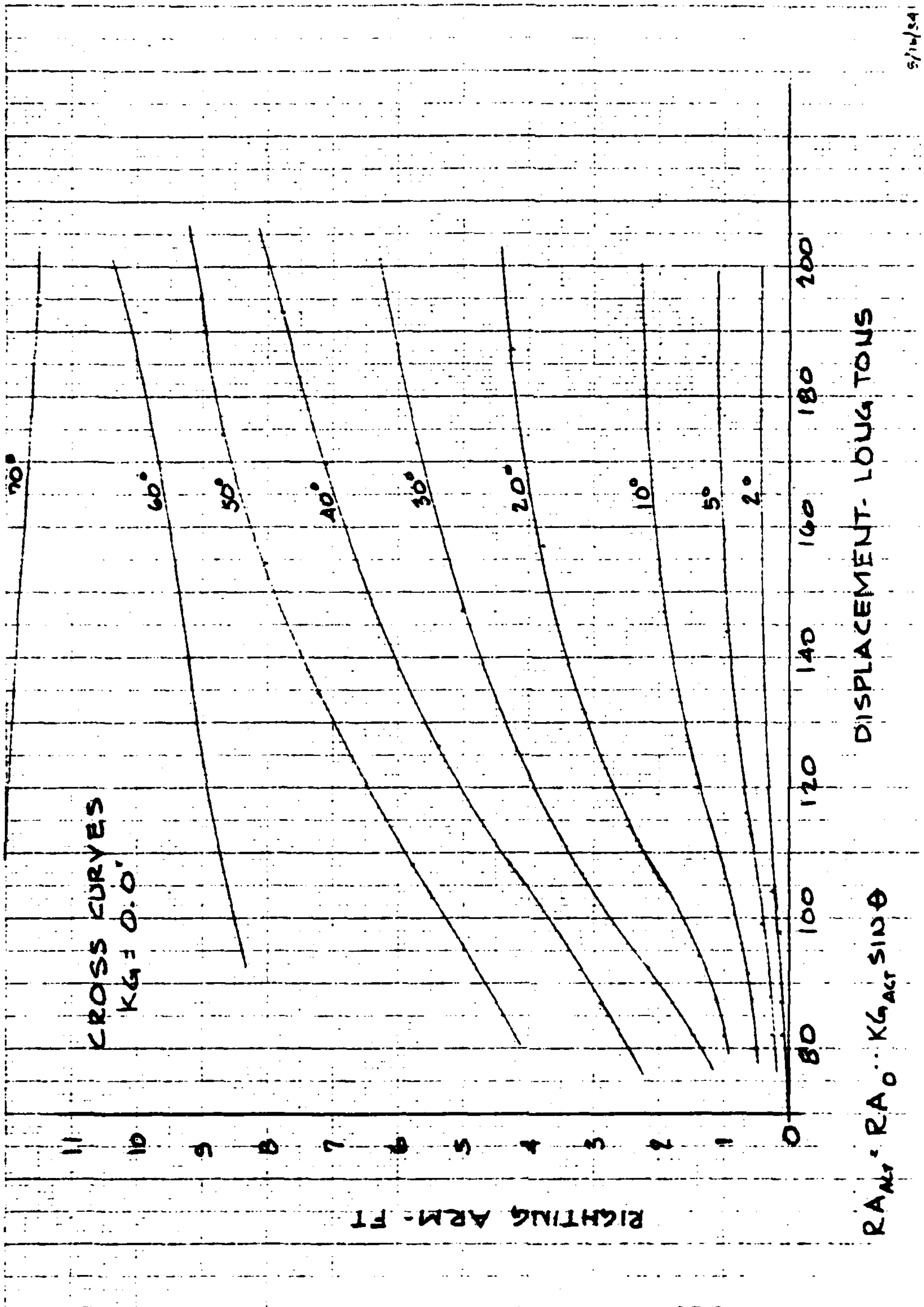


Figure 10-7. CROSS CURVES KG = 0.0'

Table 10-5

INTACT CROSS CURVES AT POLE HEIGHT = 0.01 (Continued)

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 2 DATE- 4/3/84

INTACT CROSS CURVES AT POLE HEIGHT 0.0 FEET ABOVE BL

TRIM	HEEL	DISPL	RA	TCB	VCB	LCB	DRAFT
0.0	60.000	140.378	9.200	3.252	8.745	-4.254	7.500
		169.308	9.658	3.102	9.361	-4.027	9.000
		185.937	9.997	3.059	9.778	-4.026	10.000
		201.654	10.327	3.020	10.181	-3.891	11.000
		216.694	10.618	2.968	10.547	-3.707	12.000
		228.551	10.946	2.931	10.947	-3.982	13.000
		242.391	11.148	2.844	11.231	-3.778	14.000
0.0	70.000	169.414	11.668	3.827	11.024	-4.783	7.500
		194.922	11.492	3.463	10.969	-3.902	9.000
		209.659	11.490	3.281	11.033	-3.675	10.000
		223.429	11.521	3.124	11.124	-3.455	11.000
		235.953	11.586	2.993	11.240	-3.252	12.000
		246.448	11.703	2.904	11.397	-3.089	13.000
		256.217	11.822	2.821	11.554	-2.955	14.000

Table 10-5

INTACT CROSS CURVES AT POLE HEIGHT = 0.01

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 2 DATE- 4/3/84

INTACT CROSS CURVES AT POLE HEIGHT 0.0 FEET ABOVE BL

TRIM	HEEL	DISPL	RA	TCB	VCB	LCB	DRAFT
0.0	2.000	81.943	0.102	0.000	2.897	0.917	7.500
		87.652	0.114	0.000	3.247	0.549	9.000
		91.474	0.123	0.001	3.509	0.332	10.000
		98.442	0.154	0.014	4.010	0.460	11.000
		114.835	0.259	0.082	5.090	0.473	12.000
		3.567	0.052	0.0	1.500	1.295	13.000
		177.962	0.435	0.159	7.926	-2.165	14.000
0.0	5.000	81.943	0.254	0.001	2.897	0.917	7.500
		87.652	0.284	0.001	3.247	0.549	9.000
		91.485	0.307	0.001	3.510	0.333	10.000
		98.789	0.393	0.041	4.037	0.460	11.000
		116.007	0.668	0.219	5.169	0.349	12.000
		143.880	0.965	0.390	6.613	-0.812	13.000
		178.288	1.089	0.397	7.951	-2.175	14.000
0.0	10.000	81.943	0.506	0.002	2.898	0.917	7.500
		87.652	0.566	0.002	3.247	0.549	9.000
		91.546	0.614	0.004	3.514	0.342	10.000
		100.486	0.855	0.133	4.167	0.404	11.000
		119.785	1.418	0.484	5.420	-0.097	12.000
		146.906	1.897	0.729	6.790	-1.178	13.000
		179.678	2.169	0.783	8.049	-2.250	14.000
0.0	20.000	81.943	0.996	0.005	2.898	0.917	7.500
		87.652	1.115	0.005	3.248	0.549	9.000
		94.478	1.447	0.168	3.768	0.240	10.000
		110.182	2.289	0.646	4.916	-0.529	11.000
		131.512	3.113	1.064	6.177	-1.366	12.000
		157.341	3.769	1.326	7.376	-2.086	13.000
		187.359	4.249	1.436	8.477	-2.704	14.000
0.0	30.000	81.942	1.457	0.008	2.900	0.917	7.500
		92.243	2.158	0.349	3.712	-0.006	9.000
		106.758	3.154	0.857	4.825	-1.055	10.000
		125.674	4.154	1.320	6.023	-1.952	11.000
		147.731	5.018	1.664	7.155	-2.568	12.000
		172.788	5.728	1.882	8.197	-2.961	13.000
		200.962	6.299	1.988	9.155	-3.235	14.000
0.0	40.000	86.725	2.897	0.703	3.670	-0.270	7.500
		108.404	4.323	1.278	5.203	-1.831	9.000
		126.651	5.377	1.703	6.336	-2.651	10.000
		147.223	6.309	2.032	7.394	-3.211	11.000
		169.577	7.111	2.268	8.359	-3.507	12.000
		193.731	7.781	2.410	9.233	-3.581	13.000
		218.915	8.287	2.441	9.983	-3.522	14.000
0.0	50.000	108.265	5.755	1.962	5.867	-2.729	7.500
		134.553	7.211	2.441	7.365	-3.622	9.000
		154.255	8.025	2.647	8.256	-3.910	10.000
		174.240	8.683	2.764	9.015	-4.003	11.000
		195.404	9.102	2.725	9.5[illegible]	-3.840	12.000
		214.833	9.519	2.719	10.144	-3.652	13.000
		234.300	9.848	2.661	10.623	-3.417	14.000

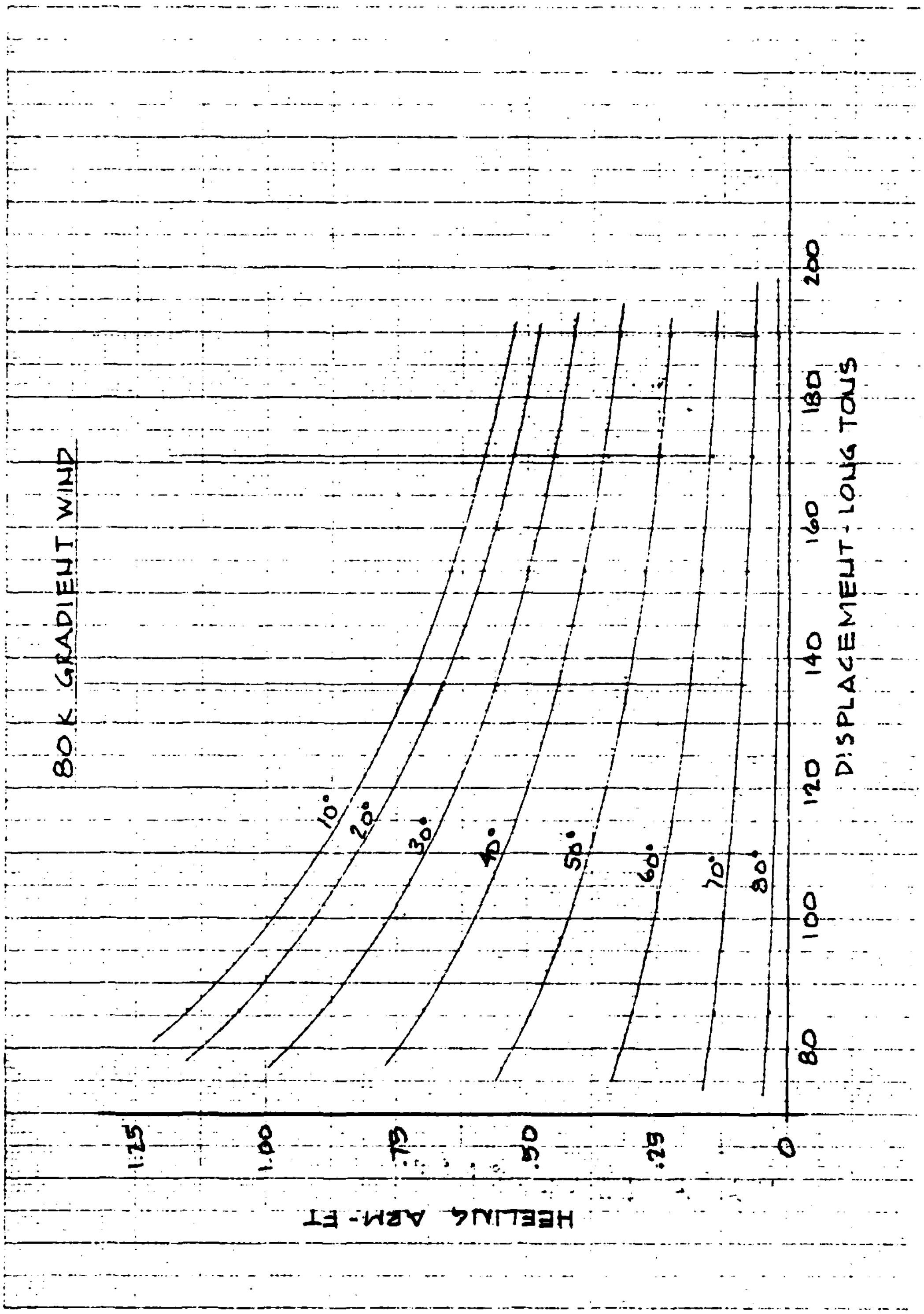


Figure 10-6. HEELING ARM CURVES - 80K GRADIENT WIND

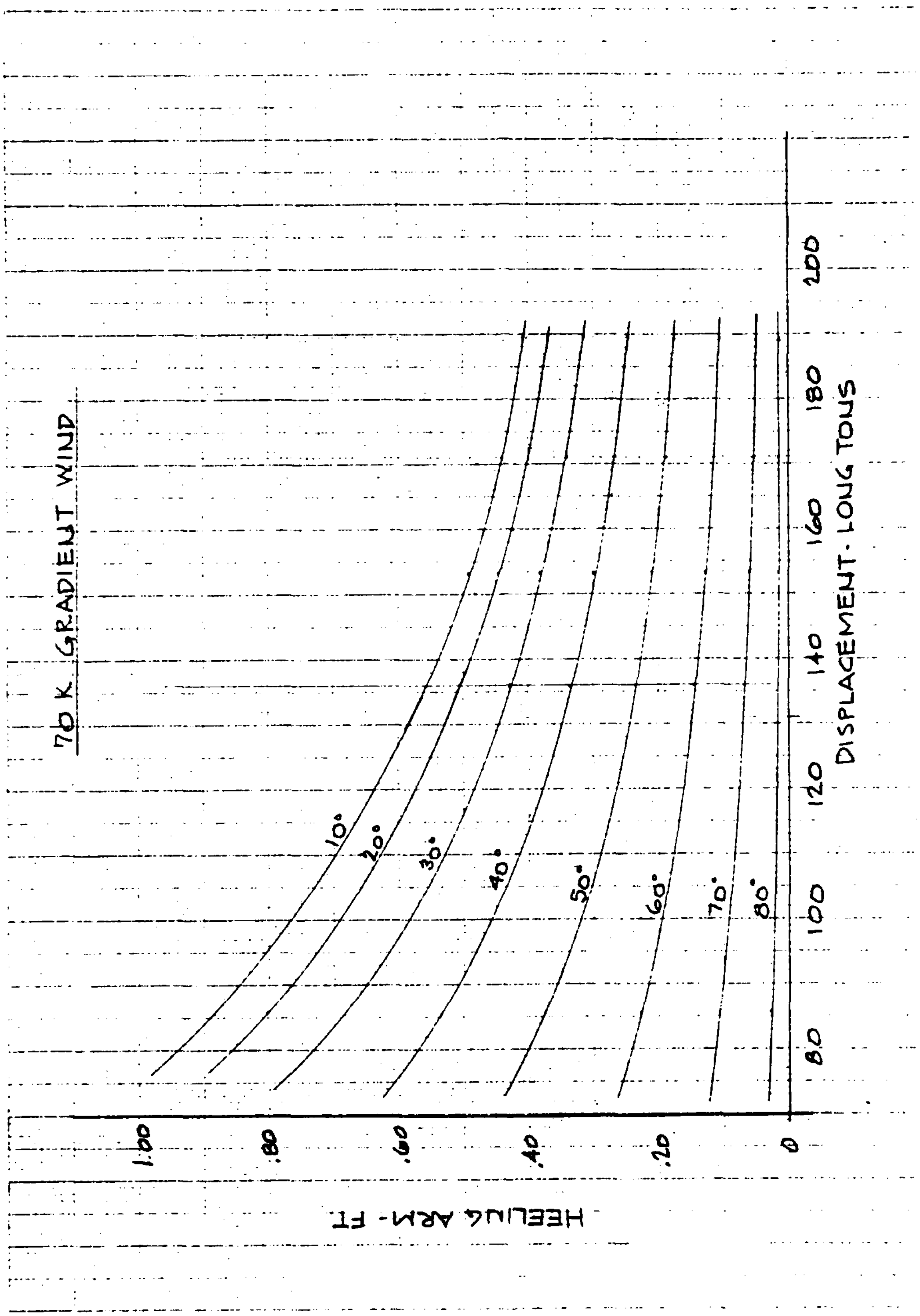


Figure 10-5. HEELING ARM CURVES - 70K GRADIENT WIND

SECTION 11

RECOMMENDATIONS

11.0 General

Careful consideration of all factors connected with the feasibility of converting a WPB into a hydrofoil with a submerged fuel tank would indicate that, while the concept appears feasible, there are several aspects of the conversion which must be addressed before proceeding with a detail design.

11.1 Stability

As previously mentioned, intact stability was of considerable concern. While wind heel stability can be obtained by the addition of the tank ballast material, it is not normally in the best interest of an efficient design to add weight to provide seaworthiness. (Although, for a demonstrator, the addition of 5 tons out of 181 tons may be considered acceptable.) Certainly, in a new design, consideration should be given to ways to lower the vertical center of gravity of the upper hull or, conversely, raising the hybrid's center to buoyancy.

The first could possibly be accomplished by relocating items such as the air tanks to a lower location and replacing the hoist and boom with a lightweight davit. Consideration should also be given to the removal of any extraneous or redundant components topside. Replacing one diesel with a gas turbine is not the panaceas it might at first appear. Although the turbine is much lighter the associated intake and exhaust installation results in a net decrease of the VCG of only about 0.15 ft.

Raising the center of buoyancy could only be accomplished by reducing the size of the B/F tank, changing its shape, or reducing strut height. While these approaches may be, in effect, counterproductive they should nevertheless be investigated further and in greater detail.

11.2 Structure

An in-depth analysis of the structural connection of the tank to the hull is a definite prerequisite of any follow-on program, particularly in light of the minimal scantlings of the existing hull.

11.3 Engine Room

The complexity of the existing engine room received only a cursory review due to the limited scope of the contract. It is obvious that besides the major relocations noted in Section 9, a number of machinery and piping alterations will be required and must be investigated.

11.4 Access Ladders

Access ladders to both the aft crew quarters and the engine room appear to interfere with conversion installations and must be carefully reviewed, particularly as relocation may entail cutting main deck beams.

11.5 New Design

It is recommended that although the WPB conversion to a hybrid form as described in this report is feasible, a new design similar to M174 design be pursued. Such a design could alleviate the intact stability issue and tightness of the diesel engine installation by a relatively small increase in upper hull beam and incorporation of light topside equipment.

11.6 Hydrodynamics

This configuration presents two peculiarities for which modest analytical effort would have substantial significance to any follow-up effort:

- Formulate the characteristics of the strut in turns as a yawed, cambered strut. Formulate the craft partially coordinated turn characteristics and establish the degree of coordination for

which no foil rolling moment is required and the corresponding turn rate and radius. Evaluate the advisability of model test confirmation of the analytical strut characteristics.

- Perform a take-off drag analysis using a characteristic unloaded hull drag curve to find out if this configuration is in that class of large/slow hydrofoil craft for which the hump take-off drag is the minimum flight speed drag. Evaluate the advisability of model measurement of the unloaded hull drag. Note that measurement of the low speed model WPB hull drag is already advised to confirm the extrapolation of Figure 4.2.3-1.

The propeller selection and diameter should be reviewed with particular regard to the low speed performance at an early stage in any follow-up effort in order to insure that follow-on design proceeds with an advantageous transmission gear ratio.

REFERENCES

1) Meyer, John R. and James H. King, "The Hydrofoil Small Waterplane Area Ship (HYSWAS)," Paper No. 76-875, AIAA/SNAME Advanced Marine Vehicles Conference, Arlington, Virginia, September 20-22, 1976.

2) Lee, Choung M. "Determination of Size and Location of Foils for 2000-Ton Hydrofoil Small Waterplane Area Ship (HYSWAS) for Vertical-Plane Stability," David Taylor Naval Ship R&D Center, Report No. SPD 648-01, November 1975.

3) MAR 298-813-1, ASW Hydrofoil Feasibility Study - Range Optimization Grumman Aerospace Corporation, August 1978.

4) MAR 298-814-2, ASW Hydrofoil Feasibility Study - Technical Study Final Report, Grumman Aerospace Corporation, November 1978.

5) MAR 298-818-1 PCH-1 HIGH POINT - Feasibility Investigation of Buoyancy/Fuel Tank Installation, Grumman Aerospace Corporation, January 1980.

6) MAR 1373-921-1, "Baseline Design Report of Extended Performance Hydrofoil Program PCH-1 Feasibility Demonstrator," Grumman Aerospace Corporation, November 15, 1981 (Rev. B).

7) MAR 298-821-1 400 Ton Hydrofoil with Buoyancy/Fuel/Tank - Conceptual Investigation, Grumman Aerospace Corporation, June 1980.

8) Russ, J.E., "Simulated Motions and Loads of an Extended Performance Hydrofoil (EPH) in Calm Water and in Waves," David Taylor Naval Ship R&D Center, Report No. SPD-1000-01, July 1983.

9) Gersten, A., "Motions and Tank Loads in Waves for an Extended Performance Hydrofoil with a Submerged Buoyancy/Fuel Tank," David Taylor Naval Ship R&D Center, Report No. SPD-0942-01, May 1980.

10) DeYoung, John, "Theoretical Symmetric Span Loading Due to Flap Deflection For Wings of Arbitrary Plan Form At Subsonic Speeds," NACA Report 1071, 1952.

11) "Hydrofoil Design Criteria and Specification; Vol. II, Hydrofoil Ship Hydrodynamic Specifications and Criteria", Grumman Aerospace Corporation, Draft in preparation.

12) Phannemiller, G.M., "Modern Design and Construction Methods As Applied to 95 ft. Patrol Boats," SNAME Chesapeake Section Paper, May 7, 1984.

13) Rossell, H. E. and L. B. Chapman, "Principles of Naval Architecture," Vol. II, SNAME, 1962.

14) Kirchhoff, Y., "Fuel Consumption on "PA4" PIELSTICK Diesel Engines", Appendix C.

15) Frauenberger, Howard C., "SHIMRIT - Mark II Hydrofoil for the Israeli Navy," 1st International Hydrofoil Society Conference Paper, Ingonish Beach, Nova Scotia, Canada, July 27-30, 1982.

APPENDIX A

USCG HYBRID CONCEPT

INPUT OFFSETS

Appendix A

INPUT OFFSETS

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION -0.650 LOCATED -2.925 FEET FROM FP

Z	Y	
22.580	0.0	
23.080	0.420	

STATION 0.0 LOCATED 0.0 FEET FROM FP

Z	Y	
13.750	0.0	
15.750	0.270	
17.750	0.670	
19.750	1.470	
22.010	3.080	BREAKPOINT
22.060	0.0	

STATION 0.100 LOCATED 0.450 FEET FROM FP

Z	Y	
1.620	0.450	
2.000	1.210	
2.500	1.370	
3.000	1.210	
3.380	0.450	
3.390	0.0	BREAKPOINT
12.750	0.0	BREAKPOINT
13.750	0.170	
15.750	0.500	
17.750	0.970	
19.750	1.810	
21.970	3.480	BREAKPOINT
22.030	0.0	

STATION 0.250 LOCATED 1.125 FEET FROM FP

Z	Y	
1.100	0.620	
1.500	1.650	
2.000	1.970	
2.500	2.060	
3.000	1.970	
3.500	1.650	
3.900	0.620	
3.910	0.0	BREAKPOINT
11.800	0.0	BREAKPOINT
12.750	0.210	
13.750	0.320	
15.750	0.780	
17.750	1.280	
19.750	2.200	
21.880	3.900	BREAKPOINT
21.950	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 0.500 LOCATED 2.250 FEET FROM FP

Z	Y	
0.600	0.800	
1.000	1.930	
1.500	2.390	
2.000	2.600	
2.500	2.680	
3.000	2.600	
3.500	2.390	
4.000	1.930	
4.400	0.800	
4.410	0.0	BREAKPOINT
11.030	0.0	BREAKPOINT
11.750	0.240	
12.750	0.450	
13.750	0.610	
15.750	1.160	
17.750	1.750	
19.750	2.730	
21.830	4.510	BREAKPOINT
21.890	0.0	

STATION 1.000 LOCATED 4.500 FEET FROM FP

Z	Y	
0.190	0.940	
0.500	2.140	
1.000	2.730	
1.500	3.070	
2.000	3.220	
2.500	3.280	
3.000	3.220	
3.500	3.070	
4.000	2.730	
4.500	2.140	
4.810	0.940	
4.820	0.0	BREAKPOINT
10.310	0.0	BREAKPOINT
10.750	0.190	
12.750	0.930	
15.750	1.840	
19.750	3.650	
22.400	5.640	BREAKPOINT
22.540	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 1.500 LOCATED 6.750 FEET FROM FP

Z	Y	
0.030	0.990	
0.500	2.300	
1.000	2.940	
1.500	3.230	
2.000	3.400	
2.500	3.450	
3.000	3.400	
3.500	3.230	
4.000	2.940	
4.500	2.300	
4.970	0.990	
4.980	0.0	BREAKPOINT
10.170	0.0	BREAKPOINT
10.750	0.420	
11.750	1.000	
12.750	1.410	
13.750	1.710	
15.750	2.530	
17.750	3.340	
19.750	4.500	
22.230	6.390	BREAKPOINT
22.300	0.0	

STATION 2.000 LOCATED 9.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	
5.010	0.0	BREAKPOINT
10.040	0.0	BREAKPOINT
10.750	0.690	
12.750	1.950	
15.750	3.170	
19.750	5.250	
22.080	7.060	BREAKPOINT
22.290	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 3.000 LOCATED 13.500 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	
5.010	0.0	BREAKPOINT
9.850	0.0	BREAKPOINT
10.750	1.210	
12.750	2.950	
15.750	4.350	
19.750	6.560	
21.790	8.090	BREAKPOINT
22.050	0.0	

STATION 3.200 LOCATED 14.400 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	
5.010	0.300	BREAKPOINT
10.020	0.300	BREAKPOINT
10.750	1.350	
12.750	3.120	
15.750	4.600	
19.750	6.770	
21.700	8.270	BREAKPOINT
21.970	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 4.000 LOCATED 18.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	
5.010	0.710	BREAKPOINT
10.320	0.710	BREAKPOINT
12.750	3.920	
15.750	5.440	
19.750	7.550	
21.520	8.790	BREAKPOINT
21.850	0.0	

STATION 5.000 LOCATED 22.500 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	
5.010	0.950	BREAKPOINT
9.880	0.950	BREAKPOINT
10.750	2.260	
12.750	4.840	
15.750	6.400	
19.750	8.300	
21.290	9.210	BREAKPOINT
21.670	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 6.000 LOCATED 27.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	BREAKPOINT
9.800	1.000	BREAKPOINT
10.750	2.750	
12.750	5.720	
15.750	7.250	
19.750	8.830	
21.110	9.500	BREAKPOINT
21.500	0.0	

STATION 8.000 LOCATED 36.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	BREAKPOINT
10.000	1.000	BREAKPOINT
10.750	3.390	
12.750	7.260	
15.750	8.530	
19.750	9.510	
20.760	9.790	BREAKPOINT
21.220	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 10.000 LOCATED 45.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	BREAKPOINT
10.150	1.000	BREAKPOINT
10.750	3.460	
12.750	8.310	
15.750	9.260	
19.750	9.810	
20.530	9.920	BREAKPOINT
20.990	0.0	

STATION 12.000 LOCATED 54.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	BREAKPOINT
10.510	1.000	BREAKPOINT
10.750	2.220	
12.750	8.720	
15.750	9.540	
19.750	9.820	
20.340	9.860	BREAKPOINT
20.800	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 14.000 LOCATED 63.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.500	2.980	
5.000	1.000	BREAKPOINT
10.960	1.000	BREAKPOINT
12.750	8.570	BREAKPOINT
15.750	9.460	
19.750	9.590	
20.220	9.600	BREAKPOINT
20.650	0.0	

STATION 15.000 LOCATED 67.500 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	BREAKPOINT
11.200	1.000	BREAKPOINT
12.830	8.560	BREAKPOINT
20.180	9.390	BREAKPOINT
20.590	0.0	

LOAD	RPM	12 PA 4 VG-DS	16 PA 4 VG
100%	1500	166 gr/HP-h	164 gr/HP-h
90%	1450	162.5 gr/HP-h	162 gr/HP-h
75%	1360	161 gr/HP-h	161.5 gr/HP-h
60%	1265	161 gr/HP-h	161 gr/HP-h
50%	1190	161.5 gr/HP-h	161.5 gr/HP-h
40%	1107	163 gr/HP-h	162.5 gr/HP-h
25%	945	172 gr/HP-h	170.0 gr/HP-h

Once again, thank you for your interest in the PIELSTICK Diesel Engines. If you have any questions, or if we may be of further assistance to you, please do not hesitate to contact us.

Sincerely yours,

ALSTHOM ATLANTIC, Inc.

Yves Kirchhoff
Manager

KY/bs

ALSTHOM
ATLANTIC, INC.

ALSTHOM
ATLANTIC, INC.

DIESEL ENGINE DIVISION

GRUMANN AEROSPACE CORPORATION
Marine Department
MS A11 C4
Bethpage, NY 11714

ATTENTION: Mr. Raymond Wright

SUBJECT: Fuel Consumption on "PA 4"
PIELSTICK Diesel Engines

Ref: 84/06/569 June 21, 1984

Dear Sir:

Following our telephone conversation of Wednesday, June 20, 1984, we are pleased to confirm the following:

For 3000 HP at the flywheel, two (2) possibilities are given:

a) 12 PA 4 VG-DS
Rated MCR 3000 HP at 1500 RPM
b) 16 PA 4 VG
Rated MCR 3200 HP at 1500 RPM

The specific fuel consumption, according to the propeller law, with following references will be:

Air temperature	27° C
Water at the aftcooler inlet	27° C
Barometric pressure	750 m/m Hg.
LHV of the fuel	10100 k cal/ky
Tolerance	+ 3%

818 HOWARD AVE. • SUITE 305 • NEW ORLEANS, LA. 70113-1108 U.S.A. • TEL. (504) 523-3203 • TELEX: 266073

APPENDIX C

PIELSTICK DIESEL ENGINE FUEL CONSUMPTION

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT- STRUT SCANTLINGS			
ANALYST	CHECKER		ANALYSIS DATE	PAGE NO.
EEH			5/4/84	B-7

STRUT PLATING   DDS 1000-4

STIFFENER SPACING = $84/3 = 28''$

WATER HEAD = $14' - 5' = 9'$-$0''$

NO PERMANENT SET $t = .25''$ - USE $5/16''$ HS

STIFFENERS

ASSUME SIMPLE SUPPORTS

$H = 9'$-$0''$

$L = 4'$-$0''$

$S = 2.33'$

$M = 49\, L^2(2H - L)S$ ''#

$M = (49)(4)^2\left[(2 \times 9) - 4\right] 2.33$

$M = 25{,}574$ ''#

$SM_{REQD} = \frac{25{,}574}{12{,}000} = 2.13\ in^3$

$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}''$ INV $\angle$ $SM = 2.21$

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - STRUT SCANTLINGS		
ANALYST: EEH	CHECKER	ANALYSIS DATE: 5/4/84	PAGE NO.: B-6

CRITICAL BUCKLING STRESS OF STRUT SIDE PLATES

ROARK PG 348 CASE 3

$$S' = K \frac{E}{1-\nu^2}\left(\frac{t}{b}\right)^2$$ - ASSUME PLTG = .313"

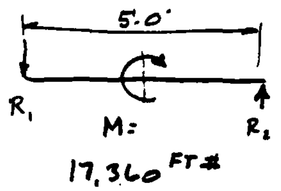
$$S' = 5.76 \frac{30\times10^6}{1-.27^2}\left(\frac{.313}{84}\right)^2$$

$S' = 2588$ psi $\qquad f_{CA} = \frac{1240\times7}{84\times.313} = 330$ psi

CHECK EXIST WEB FRAMES

ROARK PG 108 CASE 20

SIMPLISTIC APPROACH - ENDS SUPPORTED AT STANCHIONS - INTERMEDIATE COUPLE DUE TO STRUT LOAD

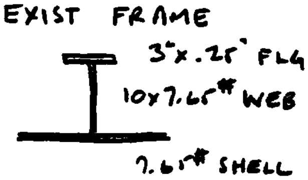


$R_1 = R_2 = \frac{17360}{5} = 3472^{\#}$

MAX $M = R_1 \times 30 + (17{,}360\times12) = 312{,}480$ "#

$S.M_{REQ'D} = \frac{312{,}480}{40{,}000} = 7.812\ in^3$ EXCLUSIVE OF EXIST LOADS.

EXIST FRAME



$I = 62.09\ in^4$

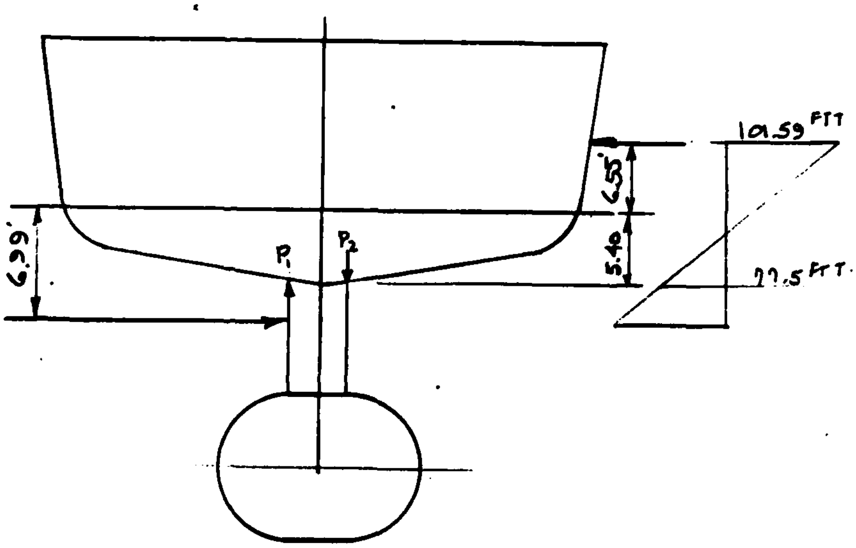
$SM = 10.95\ in^3 > 7.812$

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT- STRUT SCANTLINGS		
ANALYST: EGH	CHECKER	ANALYSIS DATE: 5/4/84	PAGE NO. B-5

ASSUME MAX SIDE LOAD MOMENT EQUAL TO 80 KNOT WIND HEEL MOMENT = 101.59 ft tons

= 227,562 ft lbs / 70 = 3251 ft lbs / ft of STRUT ATTACHMENT LENGTH.



ASSUME STRUT SIDE RTS ACT AS COUPLE ON HULL

$$P_1 = P_2 = \frac{77.5 \times 2240}{2} = 86,800^{\#}/70 = 1240^{\#}/\text{FT STRUT LGTH}$$

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT- TANK SCANTLINGS		
ANALYST: EEH	CHECKER:	ANALYSIS DATE: 5/4/84	PAGE NO.: B-4

END BULKHEADS FOR VENTED FUEL TANK AFT.

HEAD = 24'-0"

P (FUEL) = 8.68 psi

$$t^2 = \frac{3(8.68 \times 4262)}{4\pi \times 55000} = .161$$

t = .401 USE .500 HY80

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS		
ANALYST: EEH	CHECKER:	ANALYSIS DATE: 6/4/84	PAGE NO.: B-3

TANK BULKHEADS — ROARK PG 216 CASE 6

CONSIDER AS UNSTIFFENED FLAT PLT. -
ASSUME CIRCULAR PLT- 60" DIA - UNIFORM LOAD.

HY80 $S_{MAX} = 55{,}000$

$S_{MAX}\,(\text{RADIAL}) = \dfrac{3W}{4\pi t^2}$ $\quad t^2 = \dfrac{3W}{4\pi S_{max}}$ $\quad W = \pi r^2 \times 1.5\,(F.S) \times 40$

$$t^2 = \frac{3(40 \times 4262)}{4\pi \times 100{,}000} = 0.407$$

$t = .638$ (USE HY100 TO YIELD STRESS) USE .625"

$S_{MAX}\,(\text{TANGENTIAL}) = \dfrac{3W}{4\pi m t^2}$ $\quad t^2 = \dfrac{3W}{4\pi m S_{MAX}}$

$$t^2 = \frac{3(40 \times 4262)}{(4\pi)\left(\frac{1}{.27}\right)(100{,}000)} = .270$$

$t = .520$ - USE .625"

BULKHEADS BETWEEN CELLS -

UNIFORM PRESSURE BOTH SIDES - MAKE .313"

Grumman Aerospace Corporation

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
BEH			5/4/84	B-2

TANK SCANTLINGS (CONT'D)

INTERNAL BURSTING PRESSURE $P_w = 2 S_w \frac{b-a}{b+a}$

ASSUME USING HY80 $f_{tw} = 104{,}600$ psi

$$P_w = 2 \times 104{,}600 \; \frac{30 - 29.687}{30 + 29.687}$$

$P_w = 1097$ psi

FLAT TOP & BOTTOM

ROARK Pg 225 CASE 36

$$S_{max} = \beta \frac{wb^2}{t^2} \qquad \frac{a}{b} = \frac{168}{24} = \eta = \infty \qquad \beta = .750$$

$$t^2 = \frac{\beta w b^2}{S_{max}} = \frac{.750 \times 33.78 \times 24^2}{55000 \;(\text{HY80 } f_{t_{ALLOW}})} = .265$$

$t = .515"$ USE $.625"$

Grumman Aerospace Corporation
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS		
ANALYST: EEH	CHECKER	ANALYSIS DATE: 5/9/84	PAGE NO. B-1

TANK SCANTLINGS

THIN SHORT TUBE - EXTERNAL PRESSURE ROARK 4 ED PG 354 CASE 31

HEAD = 14'-0" = 6.22 psi F.S: 5

p' ELASTIC BUCKLING UNIT PRESSURE = 5 × 6.22 = 31.1 psi

$$p' = 0.807 \frac{Et^2}{\ell r} \sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3 \frac{t^2}{r^2}} = .807 \frac{(30\times10^6)\,t^2}{(14\times12)(30)} \sqrt[4]{\left(\frac{1}{1-.3^2}\right)^3 \frac{t^2}{30^2}}$$

$$31.1 = 4804\,t^2 \sqrt[4]{1.25 \frac{t^2}{900}} = 927.41\,t^{\frac{5}{2}}$$

$$t = \left(\frac{31.1}{927.41}\right)^{\frac{2}{5}}$$

$t = .257"$ USE .313" PLT

CHECK FOR INTERNAL PRESSURE ROARK PG 298 CASE 1

FUELING PRESSURE = 40 psi − 6.22 = 33.78 × 2 = 67.56 psi (F.S.)

S_1 (MERIDIONAL MEMBRANE STRESS) = $\frac{PR}{2t}$

$$S_1 = \frac{67.5 \times 29.843}{2 \times .313} = 3218 \text{ psi}$$

S_2 (HOOP WALL STRESS) = $\frac{PR}{t}$

S_2 = 3218 × 2 = 6436 psi

APPENDIX B

USCG HYBRID CONCEPT

STRUCTURAL ANALYSIS

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 20.000 LOCATED 90.000 FEET FROM FP

Z	Y	
2.000	0.0	
2.100	0.290	
2.300	0.440	
2.500	0.500	
2.700	0.440	
2.900	0.290	
3.000	0.0	BREAKPOINT
12.750	0.0	BREAKPOINT
13.230	8.170	BREAKPOINT
13.750	8.230	
15.750	8.250	
20.260	7.230	BREAKPOINT
20.490	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 18.000 LOCATED 81.000 FEET FROM FP

Z	Y	
0.240	0.900	
0.500	1.800	
1.000	2.430	
1.500	2.760	
2.000	2.940	
2.500	3.000	
3.000	2.970	
3.500	2.760	
4.000	2.430	
4.500	1.800	
4.760	0.900	
4.770	0.830	BREAKPOINT
12.040	0.830	BREAKPOINT
13.070	8.380	BREAKPOINT
20.180	8.310	BREAKPOINT
20.500	0.0	

STATION 19.000 LOCATED 85.500 FEET FROM FP

Z	Y	
0.880	0.580	
1.000	1.060	
1.500	1.690	
2.000	1.960	
2.500	2.020	
3.000	1.960	
3.500	1.690	
4.000	1.060	
4.120	0.580	
4.130	0.250	BREAKPOINT
12.390	0.250	BREAKPOINT
13.150	8.280	BREAKPOINT
20.230	7.800	BREAKPOINT
20.490	0.0	

SHIP- USCG HYBRID CONCEPT SERIAL NUMBER- 1 DATE- 4/3/84

TABLE OF OFFSETS-INPUT DATA

STATION 16.000 LOCATED 72.000 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	BREAKPOINT
11.440	1.000	BREAKPOINT
12.910	8.540	BREAKPOINT
20.150	9.110	BREAKPOINT
20.550	0.0	

STATION 16.870 LOCATED 75.915 FEET FROM FP

Z	Y	
0.0	1.000	
0.500	2.500	
1.000	2.980	
1.500	3.300	
2.000	3.450	
2.500	3.500	
3.000	3.450	
3.500	3.300	
4.000	2.980	
4.500	2.500	
5.000	1.000	
5.010	0.930	BREAKPOINT
11.650	0.930	BREAKPOINT
12.980	8.470	BREAKPOINT
20.150	8.810	BREAKPOINT
20.530	0.0	

APPENDIX D

ELECTRONIC MARKETING SYSTEMS, INC.

RESPONSE TO INQUIRY

ELECTRONIC MARKETING SYSTEMS INC.

May 30, 1984

Mr. Ed Hermanns
Grumman Aerospace Corporation
Marine Department
MS A11-04
Bethpage, NY 11714

Dear Ed:

Thank you for the inquiry concerning our products last week. Your shipboard fuel tank monitoring application sounds very interesting. As we discussed, Electronic Marketing Systems has no off-the-shelf product that meets your requirements. However, we have provided many custom turnkey computer systems to the petroleum industry.

The best approach to this application would be to use our new 16 bit industrial computer, known internally at EMS as the NAP, as the central controller of the system. Attached are two snapshots of a prototype NAP. This product is going into field test this summer and offers much flexibility and capability.

The operator interface for the system would be provided by the HARDiTerminal. This is a rugged alphanumeric display, keypad and card reader. The function keys are easily relabeled, allowing it to be used in a variety of applications.

The HARDiTerminal and NAP were designed for industrial applications and would require extensive redesign to meet military specifications. However, as you can see from the photographs, the equipment is packaged in enclosures that would require only minor modification to be suitable for shipboard use.

When you are ready to proceed with this project, we would be pleased to review your requirements further.

Regards,

Murray S. Judy
Vice President, Engineering

MSJ:sld

Enclosures

11065 SORRENTO VALLEY COURT, SAN DIEGO, CALIFORNIA 92121 TELEPHONE (619) 457-1182/8700

DAT

FILM